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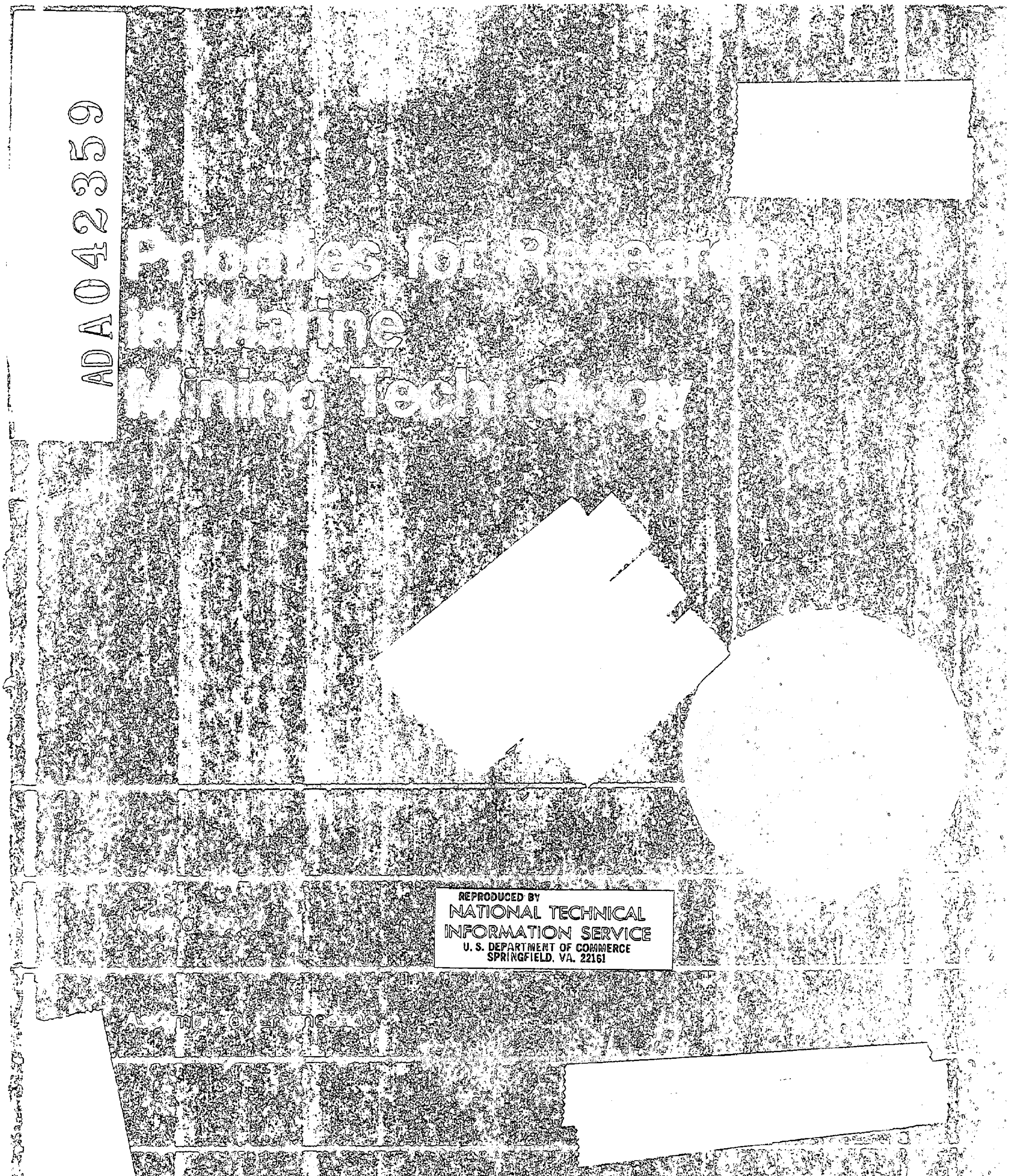

Priorities for Research in Marine Mining Technology

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Priorities for Research in Marine Mining Technology

A report prepared by the
Panel on Marine Minerals Technology
of the
Marine Board
Assembly of Engineering
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1977

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Panel responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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SUMMARY

The United States depends almost entirely on imports for some of its minerals and metals. In 1976, for instance, this country imported 98 percent of its manganese, 98 percent of its cobalt, and 71 percent of its nickel -- metals that are necessary to the electrical industry and in the manufacture of steel and steel alloys. While the United States is presently self-sufficient in copper, imports of this metal have been rising in recent years. In 1974, the value of copper imports declined due mainly to a worldwide recession, but between 1969 and 1974 the value of refined copper imports increased at a rate of almost 24 percent a year. Thus, a potential dependence on imports of copper cannot be dismissed.

Other minerals are in short supply. For example, sand and gravel, as well as construction aggregates, are becoming more scarce or more costly to acquire. Many existing land sites are being rapidly depleted or, because of their nearness to expanding urban areas, are being taken over for housing or industrial purposes.

The oceans represent the biggest potential storehouse for many of these metals and minerals. Nickel, copper, cobalt, and manganese are to be found in manganese nodules that lie on the ocean floor. At least four U.S.-based companies and their international partners[1] recognize the economic potential of these nodules and have been involved in exploration and research and development programs to mine them from the ocean depths. Sand and gravel, in addition to placers, shell, and phosphate rock, are located in the shallow and intermediate waters off the continental United States, its islands and territories, and the state of Hawaii. However, the exploration and recovery operations for these materials does not match in size the effort being expended by the deep ocean mining industry for manganese nodules. The sand, gravel, and shell shallow-water dredging industry consists of small companies, geographically scattered, with limited capabilities for major developmental work.

As a result of the increasing interest and activity in ocean mining, the Administrator of the National Oceanic and Atmospheric Administration (NOAA) requested the National Research Council to review the technology and technical services needed for the orderly development of an ocean mining industry and the methodology for determining the possible environmental impact of such activities. Accordingly, the Marine Board of the NRC appointed a special panel that initiated a study of the problems in June 1976.

At the beginning of its study, the panel found that the technologies and methodologies for ocean mining, other than sand and gravel, are well advanced. However, the panel found a need for improvement in existing tools, procedures, and services for marine minerals assessment. The preliminary delineation of seafloor areas containing mineable concentrations of ore-grade minerals requires adequate data and information on bottom topography and sediment characteristics, distribution, and thickness. Site-specific exploratory surveys require detailed bathymetric mapping, geophysical profiling, bottom photography, TV viewing, and seafloor sampling for surface and subsurface sediments. Such information is a prerequisite for developing any mining strategy. This information, along with data on weather, sea conditions, and currents, is necessary to proceed with a technically and economically sound program, in a reasonable time period, for the production of ores.

The panel found that, overall, the present weather and sea forecasting services provided by the government are adequate for most ocean mining purposes. The exception occurs on the outer continental shelf where localized, site-specific forecasts are less than adequate, primarily because extensive data coverage is lacking on a real-time, continuous basis.

The panel also found substantial technical shortcomings in the navigation systems available for marine minerals exploration and mining. During prospecting surveys, large areas must be covered, and position accuracy must be on the order of the size of the deposit. Present systems, including hyperbolic and satellite navigation, are usually adequate for these efforts, but for operations far from land, such methods need to be improved significantly.

The panel reviewed the possible effects of marine mining equipment on the environment, as well as the structural loads on the equipment likely to be imposed by environmental forces. It gave considerable attention to methodologies for environmental studies in view of increasing concern for the environmental implications of ocean mining and marine minerals processing operations. For example, dredging devices used in deep ocean mining may disturb a strip of the ocean floor that could result in a surface discharge of nutrient-rich bottom water containing suspended sediment and fine particles of manganese nodules. Mining of sand, gravel, shell, and heavy metals placer deposits could alter the topography of the area and, in some cases, alter the currents and rates of sediment transport in the areas surrounding the mined site. Moreover, the processing of deep ocean minerals or of phosphorites, sulphates, and barites will result in tailings, which leads inevitably to disposal problems.

The panel concluded that the predictive capability of environmental studies would be enhanced if research efforts were focused on those components of the ecosystem most sensitive, given the type of mining-induced impact and the characteristics of the affected ecosystem. It is critical to develop an experimental approach in which specific questions and hypotheses are formulated for testing on appropriate studies, rather than using the current practice of broad environmental studies employing "baseline" techniques.

The panel reviewed the adequacy of the present environmental impact statements (EIS) with respect to ocean mining. In the past, the absence of sufficient documentation has led, in some cases, to uncertainties about the thoroughness of an EIS and such uncertainties resulted in litigation. Clearly, there is a need to reach an accommodation between mineral recovery from the oceans and the harm that might be caused to the environment. Often a preliminary assessment on a priori grounds can be made, which would include an accommodation between conflicting goals. That avenue is considered appropriate to pursue. More frequently, the issue will be more complex, and professionals in the concerned disciplines may agree that more detailed examination is warranted. But in all instances, non-specific data collection should be avoided.

The U.S. deep ocean mining industry has engaged in extensive scientific and technical research and development, and the indications are that it will continue these activities. Nevertheless, the panel concluded that federal government support of basic research in some areas may be appropriate. The government might also be of assistance in facilitating the orderly development of the offshore sand

and gravel and shell dredging industry, expanding services such as weather forecasting and facilitating the exchange of technical information.

In making its recommendations, the panel used the following criteria:

- The recommended action, if implemented properly, would be likely to encourage the development of technologies, environmental methodologies, and/or services that enhance the ocean mining capability, and

- The recommended action, if implemented properly, would be likely to meet environmental concerns with respect to ocean mining.

The following recommendations, which are elaborated in the report, are presented here in the order of the panel's priorities:

1. Environmental impact studies of marine mining should be redirected toward the testing of theoretical constructs and scientific hypotheses associated with ecological processes in the vicinity of the mining site. The development of such a methodology is the responsibility of relevant federal agencies.

2. A specific set of procedures for final reporting, for draft guidelines, for the resolution of significant issues, and for administration are to be followed by the government for incorporating studies into the EIS process.

3. Government weather services and sea state information should be improved in accuracy, distributed more timely, and expanded to include potential and actual nodule mining areas in the Pacific and hard mineral mining locations along the continental shelf.

4. Government supported research should be undertaken on the genesis and regeneration of shell and placer deposits in order to increase the understanding required

for evaluating mineral deposits, preserving the environment, and designing and developing mining and beneficiation systems.

5. Data should be acquired by the government for the preparation of high-resolution bathymetric charts, with contour intervals of 5 to 10 meters for those areas of potential mineral deposits on the U.S. continental shelf.

6. The federal government should encourage the rapid development of the Navigation System with Timing and Ranging (NAVSTAR) global positioning system or its equivalent and foster the development of improved subsurface acoustical location fixing systems required for ships underway in planned ocean mining operations and in related environmental investigations.

7. The government should support detailed studies of the processes of metal concentration where these processes occur at oceanic ridges, as well as the processes involved in the transfer of metals concentrated in oceanic crust to continents and islands. Such studies are necessary in order to determine the metallic mineral potential of ocean crust. To engage in such studies, a new generation of oceanographic equipment and instrumentation is needed.

8. The federal government should promote the voluntary exchange of technical information among the ocean mining industry and relevant government agencies and academic institutions.

9. The federal government should explore with other nations the feasibility of voluntary exchange of research information and of jointly planned and executed research programs for assessing environmental effects caused by ocean mining.

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INTRODUCTION

This report is the result of a study by a panel organized under the Marine Board, Assembly of Engineering, National Research Council, and deals with selected aspects of the mining of hard minerals in the deep ocean and on the outer continental shelf (OCS) and the possible environmental impact of these activities.

In undertaking this study, the panel was requested by the National Oceanic and Atmospheric Administration (NOAA) to identify, assess, and evaluate the technological needs and relative roles of the federal government and industrial sector for mining hard minerals in territorial and international waters and, thereby, advance the orderly industrial development in an environmentally safe manner in the years between 1980 and 2000. The panel was also asked to consider:

- the technological needs of the federal government and the commercial sector;
- technology transfer between (and within) the federal government and the commercial sector;
- requirements for technical federal services such as weather information;
- factors which may impede further technological development, such as environmental, legal, economic, and training and education; and
- relative roles of the federal government and the commercial sector.

The panel began its work by a consideration of two previous studies of the Marine Board relating to marine mining technology. The report of the first study completed in 1976, Seafloor Engineering: National Needs and Research Requirements, examined the national needs for seafloor activities, reviewed research required to advance the capabilities for seafloor engineering and the procedures by which the federal government could foster needed research programs.[2] The second study resulted in a report, Mining on the Outer Continental Shelf and in the Deep Ocean, in 1975.[3] This study considered the potential of the various marine mineral resources, and evaluated the technological state-of-the-art in both OCS and deep ocean mining. Legal, regulatory, and jurisdictional problems were reviewed together with the potential environmental impacts of mining.

Additionally, two conferences resulted in papers and discussions that were considered by the panel. In March 1976, a marine minerals workshop was sponsored by NOAA.[4] In June 1976, the National Planning Conference on Commercial Development of the Oceans was held, during which the mining of hard minerals, the status of the industry, and the major problems impeding commercial recovery of minerals were reviewed.[5]

Because the technologies and methodologies for ocean mining, particularly in the deep ocean, are well advanced, the panel decided that the study that is the subject of this report would be limited in focus to the technology and methodology for resource assessment and the determination of environmental impact information. The roles of the private sector and the government in providing technical services and facilitating the diffusion of technology and technical information were also to be examined. The study would exclude consideration of maintenance dredging in channels and on beaches, as well as the recovery of petroleum and hydrocarbon minerals. Needs for training, education, operational procedures, and logistics in support of offshore mining were also to be excluded from the study. Potential legal, economic, and other barriers to the development of the ocean mining industry were to be considered only as these influenced the future technological advancement of the industry. Jurisdictional issues, such as the 200-mile economic zone, were deliberately excluded from the study.

This report is not meant to be considered a primer or review of ocean mining activities or the justification of ocean mining to meet national needs. References listed in the bibliography to this report are intended to provide an opportunity for the concerned reader to become more informed on the subject of ocean mining.

Much of the data for this report is drawn from those references. The report also draws heavily upon working papers prepared by several members, as well as the discussions that took place during a workshop convened by the panel in January 1977. This workshop addressed resource assessment and the methodology of environmental impact assessment and reviewed recent studies of current ocean mining systems and their capabilities. A list of these working papers, which are available from the Marine Board, is included in this report as Appendix A. Workshop participants are listed in Appendix B.

MINERAL RESOURCES IN THE OCEAN

Manganese nodules and oceanic crusts and pavements are the most likely sources of deep-sea minerals to be recovered in the foreseeable future. Composed of fine-grained oxide material, they are distributed widely over the floors of the world's oceans. While they vary widely in their physical and chemical composition, their components are primarily metals -- chiefly manganese, iron, nickel, copper, and cobalt. The importance of these minerals to the U.S. economy has been extensively described in a number of reports including one of the background papers prepared for the panel by James L. Johnston.[6] In the Report of the Comptroller General of the United States to The Honorable Lee A. Metcalf, Chairman, Subcommittee on Minerals, Materials, and Fuels of the U.S. Senate Committee on Interior and Insular Affairs, it is stated that:

> Federal Government reports show that there is an increasing domestic and worldwide demand for these four metals. They also show that known commercially recoverable land-based resources are limited, whereas manganese nodule deposits on the deep seabed are virtually unlimited.
>
> The nodule deposits are of particular importance to the United States. Although we produce 85 percent of our copper requirements, we produce less than 10 percent of our needs for nickel, cobalt, and manganese. These metals are critical to the electrical industry and in the manufacture of steel and steel alloys. Studies indicate that recovery of the four metals contained in the manganese nodules by U.S. firms could result in this country
>
> --becoming independent of foreign suppliers in meeting national security needs for these metals and

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--exporting these four metals, thus turning a projected $6 billion balance of payments deficit for these metals into a surplus by the year 2000.

Resource-rich third-world nations are beginning to exert more control over their mineral resources, as demonstrated by the recent oil embargo and by third-world nations' demands for a new world economic order. An August 1974 Stanford Research Institute report, "Strategic Resources and National Security," ranked manganese, cobalt, and nickel among the most critical materials which would affect national security if shortages occurred.[7]

The reliance of the U.S. on imports for these minerals is shown in Table I.

On the basis of known quantities, average compositions, and operating conditions, nodule sites in the Pacific have attracted the greatest attention. Indeed, the greatest concentration of nodules relatively high in copper and nickel is believed to be in the eastern equatorial North Pacific. This nodule zone occupies about 13,000,000 square kilometers (the total Pacific Ocean is some 39,000,000 square kilometers). One industrial firm has laid claim to ore deposits in an area of 60,000 square kilometers, to be mined over a 40-year span. Figure 1 shows the world distribution of surficial marine manganese nodule deposits based on core and dredge data.

Characteristically, nodules in the regions of potential interest are 2 to 10 centimeters in diameter, lying on the surface of the ocean floor at depths of 5,000 meters. The substrate is typically siliceous ooze or "red clay" with an average particle size of 2 microns and with variable thickness. The mineral sites that are chosen have a minimum of topographic expression -- i.e., they are in regions of gentle rolling hills. It is estimated that about 75 percent of a mineral site is suitable for mining. About 90 percent of the nodules appear to occur at the sediment surface with a surface density of about 10 kilograms (wet) per square meter in areas of potential commercial interest. So-called micronodules (< 200 microns in size) are known to occur within the sediments.

TABLE I

NET IMPORT RELIANCE OF SELECTED MINERALS AND METALS AS A PERCENT OF CONSUMPTION IN 1976

MINERALS AND METALS	NET IMPORT RELIANCE* AS A PERCENT OF APPARENT CONSUMPTION**	MAJOR FOREIGN SOURCES (1972-1975)
COLUMBIUM	100	BRAZIL, THAILAND, NIGERIA
MICA (sheet)	100	INDIA, BRAZIL, MALAGASY
STRONTIUM	100	MEXICO, U.K., SPAIN
COBALT	98	ZAIRE, BELGIUM-LUXEMBOURG, FINLAND, NORWAY
MANGANESE	98	BRAZIL, GABON, AUSTRALIA, SOUTH AFRICA
TANTALUM	94	THAILAND, CANADA, AUSTRALIA, BRAZIL
TITANIUM (rutile)	93	AUSTRALIA, INDIA
PLATINUM GROUP METALS	92	U.K., U.S.S.R., SOUTH AFRICA
BAUXITE & ALUMINA	90	JAMAICA, SURINAM, GUINEA, AUSTRALIA
CHROMIUM	89	U.S.S.R., SOUTH AFRICA, PHILIPPINES, TURKEY
TIN	85	MALAYSIA, THAILAND, BOLIVIA
ASBESTOS	83	CANADA, SOUTH AFRICA
FLUORINE	79	MEXICO, SPAIN, ITALY
NICKEL	71	CANADA, NORWAY, NEW CALEDONIA
GOLD	70	CANADA, SWITZERLAND, U.S.S.R.
MERCURY	65	CANADA, ALGERIA, MEXICO, SPAIN
CADMIUM	64	CANADA, MEXICO, AUSTRALIA, BELGIUM-LUXEMBOURG
POTASSIUM	62	CANADA
ANTIMONY	61	SOUTH AFRICA, P.R. CHINA, BOLIVIA, MEXICO
SELENIUM	59	CANADA, JAPAN, MEXICO
TUNGSTEN	59	CANADA, BOLIVIA, PERU, THAILAND
ZINC	59	CANADA, MEXICO, AUSTRALIA, PERU, HONDURAS
TELLURIUM	57	PERU, CANADA
SILVER	47	CANADA, MEXICO, PERU
PETROLEUM (inc. Nat. Gas liq.)	41	CANADA, VENEZUELA, NIGERIA, SAUDI ARABIA
BARIUM	38	IRELAND, PERU, MEXICO
GYPSUM	38	CANADA, MEXICO, JAMAICA
TITANIUM (ilmenite)	37	CANADA, AUSTRALIA
IRON ORE	35	CANADA, VENEZUELA, BRAZIL
IRON & STEEL SCRAP	(-22) NET EXPORTS	
VANADIUM	31	SOUTH AFRICA, CHILE, U.S.S.R.
ALUMINUM	22	CANADA
COPPER	15	CANADA, PERU, CHILE, SOUTH AFRICA
LEAD	15	CANADA, PERU, AUSTRALIA, MEXICO
STEEL MILL PRODUCTS	10	JAPAN, EUROPE, CANADA
SALT	7	MEXICO, CANADA, BAHAMAS, CHILE
NATURAL GAS	4	CANADA
CEMENT	3	CANADA, BAHAMAS, NORWAY, U.K.
PUMICE	2	GREECE, ITALY

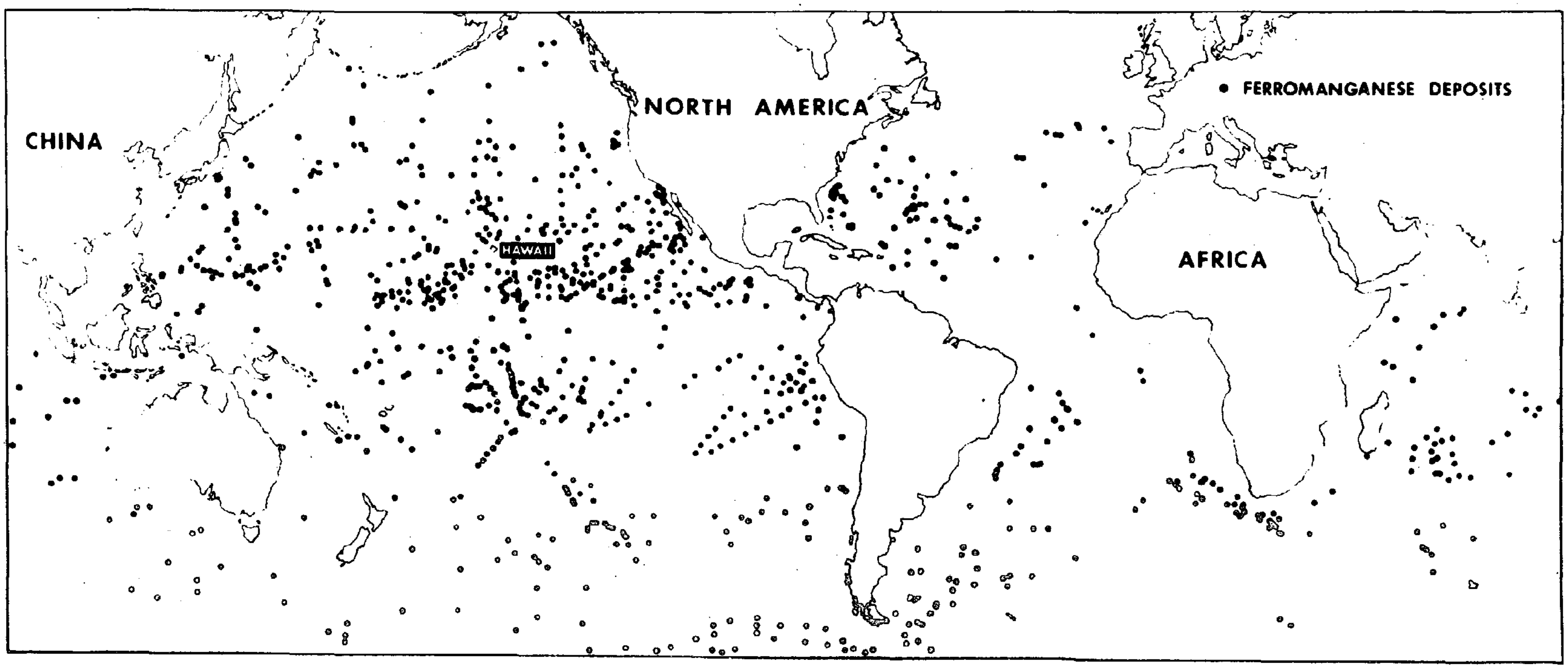
*NET IMPORT RELIANCE = IMPORTS-EXPORTS + ADJUSTMENTS FOR GOV'T AND INDUSTRY STOCK CHANGES (EXCEPT FOR PETROLEUM AND NATURAL GAS).

**APPARENT CONSUMPTION = U.S. PRIMARY + SECONDARY PRODUCTION + NET IMPORT RELIANCE. PETROLEUM AND NAT. GAS INCLUDES INDUSTRY STOCK CHANGES

BUREAU OF MINES, U.S. DEPARTMENT OF THE INTERIOR (import-export data from Bureau of the Census)

FIGURE I

World Distribution of Surficial Marine Manganese Nodule Deposits
Based on Core and Dredge Data



Source: Horn, D., B. Horn, and M. Delach, 1972. Worldwide Distribution and Metal Content of Deep-Sea Manganese Deposits in Manganese Nodules in the Pacific, Symposium/Workshop Proceedings, October 16-17, 1972. Department of Planning and Economic Development, State of Hawaii, pp. 46-60.

Samples of benthic megafauna in the eastern equatorial North Pacific indicate average weights of 0.8 gram per square meter. Bottom currents in the area average about 7 centimeters per second with peaks of up to 20 centimeters per second.

Manganese and iron oxide compounds slowly accumulate on the surfaces of all current-swept rock outcrops that appear on the deep sea floor. These compounds accumulate on sediment-covered bottoms (except where sedimentation rates are high) in the form of nodules and are found as well in areas with bottom ocean currents. The growth rate of manganese nodules, estimated at 10 million tons per year in the Pacific, has led some writers to claim the nodules are a renewable resource. Radiochemists, on the contrary, have determined that manganese accumulates very slowly on crusts and nodules at rates of 2-15 millimeters per million years. The accumulation rate of the sediments on which the nodules lie has been measured at about 1-2 millimeters per thousand years. This apparent paradox remains one of the principal scientific questions related to nodule genesis.[8]

Metallic minerals other than manganese nodules present in oceanic crust may constitute another major resource. These marine metallic minerals commonly occur in three forms. Metalliferous sediments that lie on oceanic crusts are one known form. They occur in all the ocean basins, but the only known metalliferous sediments with sufficiently high metal concentrations, and in volumes large enough to have possible economic value, occur in the Red Sea. Encrustations of metallic oxides that adhere to oceanic crusts are another form of marine metallic minerals. Relatively thick encrustations (less than one meter) are so far known to exist in several locations on the mid-Atlantic Ridge and one location on the East Pacific Rise system. Massive sulfide deposits that occur within the oceanic crust constitute another form of marine metallic minerals. These are known to exist when slices of oceanic crust are exposed in certain islands and on continents, and they represent an important source of ore deposits. Their presence in ocean basins is inferred, but not yet demonstrated, mainly because the sampling of oceanic crust is difficult.

Although only a very small percent of the deep seafloor has been extensively surveyed, enough has been learned about the extent and location of the surficial deposits to permit the first steps of commercial development. One hundred years after they were first brought up from the ocean floor, deep-sea mining techniques for manganese nodules are being pursued by four United States-based companies as well as by some foreign firms. The U.S. companies have entered into consortia arrangements with foreign partners. By July 1976, the cost of the R&D programs was reported to be approximately $25-$30 million per company, and the costly phase of full-fledged exploration was about to begin in order to arrive at detailed assessments of the potential sites, nodule composition and chemistry, and the characteristics of the seafloor.[9]

As the preparatory work by ocean mining firms demonstrates so far, a long planning horizon is required for exploration, recovery, production, and distribution. Consequently, milestones for acquiring particular assets are planned well in advance and need to be attained by the industry in an orderly way. The deep ocean mining industry faces two uncertainties that can affect its investment climate: (a) the extent of federal regulation of ocean mining, and (b) unresolved issues being considered by the U.N. conferences on the Law of the Sea.

Minerals on the Continental Shelf

In the shallower continental shelf areas of the U.S., relatively few efforts are underway to recover sand and gravel, phosphates, placers, and other minerals. However, the demand for sand and gravel for construction fill and other industrial uses is increasing as supplies decrease on land because of depletion or the reluctance of communities to allow aggregate mining. Many sources of sand and gravel are located near urban centers where the construction industry is the most active. As land sources are exhausted, new ones must be found. The farther the source is from the construction industry it supplies, the more expensive the sand and gravel becomes because of the cost of transporting it to the ultimate user.[10]

Domestic supplies of phosphate rock, from which fertilizer is produced, come from terrestrial deposits such as in Tennessee, North Carolina, and Florida. These reserves are expected to be depleted in the 1990's, but there are known reserves in Idaho, Montana, Utah, and Wyoming. Moreover, offshore production for this mineral has not begun.[11]

Academic research on marine placers began relatively recently, supported by the NOAA Sea Grant program and several American mining and petroleum firms. This research, which has focused on locating marine placer deposits, assessing both high energy and low energy placers and determining the origin and distribution of placer deposits, has laid the foundation for a placer mining industry in the U.S. As a result, a growing list of American companies and consortia are pursuing marine placer programs in U.S. waters, although their efforts are largely confined to exploration.[12]

There has been moderate activity in the recovery of shell in the Gulf of Mexico, principally in Texas, Louisiana, and Alabama, confined largely to bays and estuaries. Overseas, the United Kingdom production of aggregates from offshore deposits in 1970 was approximately 14 million tons, or about 13 percent of the total production from all sources, and the percentage has been steadily increasing since 1970. The United Kingdom marine sand and gravel mining industry is probably the largest and most advanced offshore mining operation of its type in the world, supplying increasingly large portions of the concrete aggregate for the construction industry in the U.K. and the nations bordering the North Sea on the European continent. There are some 32 different companies operating more than 75 sand and gravel sea dredgers in the U.K., with a total capital investment of over $100 million. Sand and gravel are also economically mined from the seafloor in Japan.

Because these minerals are found relatively close to shore, the recovery of coastal deposits, unlike deep sea mining, occurs within the legal purview of coastal states. A stable body of law defines property rights and institutions for the settlement of disputes. However, this may change due mainly to the establishment of local government groups with authority to override previous decisions. Except for special situations, mineral recovery from coastal areas will remain economically marginal for some time to come. The high cost of operating on floating platforms and transporting the materials, the uncertainties of market conditions, and the lack of uniformity in tax treatment detract from the future return of these offshore ventures.

The Location of Mineral Resource Beds in the Continental Margins

As Moore has noted in his background paper prepared for the panel, the only detailed small scale maps and charts presently available for marine mineral deposits areas are those in the confidential files of a few companies, in the working (open) files of a few academic teams, located at the universities of Wisconsin, Alaska, and Georgia, or in the Marine Branch of the U.S. Geological Survey, NOAA, and the Bureau of Mines.[13]

New England Waters

This area has already been proved abundant in sand and gravel resources by NOAA scientists, and may well come to production before any other offshore area along the Atlantic seaboard. Additionally, it is known that glauconite (a fertilizer) is present on parts of the shelf and concentrated on the bottom on Georges Bank. Heavy minerals have been reported in abundance in parts of Buzzards Bay, in the Gulf of Maine, and in certain coastal zones in Long Island Sound. The only marine mining in the New England area was carried on for zinc and other sulfide metals beneath Penobscot Bay, Maine.

Central and S.E. Atlantic Offshore

From the crystalline rocks of the Piedmont and near-coastal areas, the following detrital minerals are, or could be, formed in marine placers: rutile, ilmenite, zircon, rare earths (RE), minerals, and gold. Phosphate is present beneath several coastal bays, such as in the Sapelo area, and inland along the coast; it is also likely to be found offshore. Of the non-metal deposits, shell is already produced, sand is becoming more important, and detrital glauconite could be a profitable by-product. Commercial exploitation is underway near Tonis River, New Jersey, and by firms at Trail Ridge, Florida. Surveys have confirmed the existence of gold in coastal sands near Pimlico Sound, North Carolina. The offshore Blake Plateau is known to have abundant ferro-manganese nodules, which could be an economic source of manganese and catalytic grade nodules.

Gulf of Mexico

On the Florida coast, shell, carbonate sand, and possible construction (reef) rock are potential resources. The phosphate deposits are as yet unproved. Some heavy minerals are known to be present along the mid-Gulf coast. Off the Mississippi River delta and other continental slope sites where the oxygen minimum layer intercepts the bottom, finely disseminated, metal-bearing sulfide minerals are formed in situ. These deposits are only partly known, largely due to lack of carefully placed cores and grab samples. Along the Texas coast, oyster shell recovery is a commercial enterprise in the bays, but, as yet, it has not moved to OCS waters.

Extensive dredging for clam shells has proceeded in Lake Pontchartrain, Louisiana and Mobile Bay, Alabama, and oyster shell dredging has been carried on in Matagorda and San Antonio Bays, Texas. Most of the shell has been removed from Galveston Bay, Texas, except from the areas close to live oyster reefs. It is expected that since the dredged areas will be repopulated in time, the shell resource can be considered renewable.

During the late 1960's, scientists from the U.S. Geological Survey (USGS) identified large areas of heavy minerals off the Texas coast but the grade and quantity of these deposits is unknown.

West Coast

In the late 1960's, USGS personnel reported detrital gold off the California coast, chiefly off Crescent City. Other areas are known to possess fine placer gold, including sites off Oregon. Seamounts and buried mountain ridges in the offshore California borderland are topped with phosphorite, but they have not been mined. Coastal waters are already dredged for sand, and evaporite salt is commercially produced in San Francisco Bay. Although intrinsically not a mineral, biogenic iodine can be mined from the kelp beds of California. Other noble and transition metals may also be present in sub-sea lode deposits off the West Coast.

Alaskan Waters

Unquestionably, the richest potential offshore mineral deposits are those known, or most likely present, beneath Alaskan waters. Alaska has the longest coastline and the major share (over 50 percent) of adjacent continental shelf of all of the United States. The potential yield of new marine mines in Alaskan coastal and OCS waters, chiefly the southeast Alaskan inlets and the Bering Sea shelf, is the greatest of any area under the U.S. flag.

The list of minerals and metals to be found is long. Barite and gold are already in production. Other marine minerals and metals include copper, platinum, osmium, nickel, cobalt, tungsten, tin, uranium, titanium, mercury, vanadium, chromium, rare earths (particularly holmium), manganese, lead, zinc, and, in special sites, sand, gravel, shell, organo-metallics, and possibly fertilizers. The big problems facing the marine miner in this area are largely constraints imposed by nature (ice cover, high seas, depths, and remoteness). Nevertheless, offshore Alaska may well be the last great metals storehouse.

Insular U.S. Possessions, States, and Trusts

Surprisingly, for all their real and possible potential, the overseas insular areas of the United States are seldom mentioned in marine commodity assessments. Yet, the potential aggregate underwater mining site is about equal to one-third of the coterminous United States.

Puerto Rico and U.S. Virgin Islands. The obvious resources, of course, are carbonate (lime) sands and lutites, construction (reef) rocks, and shell. However, volcanic-related metals, including mercury and certain transition elements (in the anoxic slope) are all possible offshore.

American Samoa. Carbonate sand, some phosphorite offshore, and volcanic-related metals may be found.

Hawaiian Archipelago. Carbonate sands, ferromanganese crusts nearshore, plus nodules may be found in "nearby" deeps. Based on a partial analysis, the potential for noble metals and selected transition metals is still favorable.

Palmyra. There is a possibility that transition metals will be found at depth. The area, however, is totally unexplored.

U.S. Trust Territory. This vast area has tremendous potential. From metal deposits on land mined previously by the Japanese the presence of economically interesting minerals for the region is known. It is suggested that the following should be present beneath trust territory waters: copper, zinc, lead, gold (and possibly platinum), chrome, and rare earths. The mining of phosphorite may soon prove to be profitable, with carbonates as a source for meeting new lime needs in Southeast Asia. The region is large, unknown in a mineral sense, and remote -- yet its potential yield is large.

RESOURCE ASSESSMENT

Resource assessment is an activity for locating new ore beds, quantifying the dimensions and qualities of the mineral deposits, determining characteristics of the deposit such as its mineability, and fixing its geodetic position. Fundamental to a meaningful resource assessment program is the knowledge of the genesis of marine deposits, availability of hydrographic charts of known, probable and possible marine mineral resource areas, available metals data from seafloor sediment analysis, and understanding of metallurgical-processing characteristics in order to determine the economic potential of the deposit.

Potential mine sites in U.S. waters range from the polar seas to the equatorial tropics. Additionally, the water depths vary from the beach at low tide and some 1000 meters at potential slope deposit mineral sites, to some 5000 meters at manganese nodule sites, so that the tools for acquiring this knowledge vary with the type of resource being located and quantified, and upon the characteristics of the water column and sea bed being explored.

Mineral exploration and assessment on land typically begin with a review of available topographic, geologic, and photo maps and geological data for the area. Satellite and aerial photographs are available for this purpose, in addition to information on the regional geology. For the ocean, however, little of this information exists. Major naval and shipping channels or areas of extensive oceanographic research are charted bathymetrically, but not necessarily with the precision required for mining. Geological information exists for regions currently being exploited for minerals and petroleum. Geological extrapolation from land masses offers additional clues. However, the total of this information for the typical exploration activity in the shallow areas is marginal -- even for developing and exploration strategy -- and in the deep ocean its contribution to exploration is almost non-existent.

Geological and geophysical maps and charts of moderate scale, which indicate the surface and subsurface geological-geophysical features of the sea floor, are required for preliminary prospecting and surveying of potential ocean mining sites on the continental shelf and deep ocean. Specifically, information is needed on the composition, thickness, and extent of sediment cover, the stratigraphic and structural relations of the bedrock, geologic cross sections and generalized submarine gradients, seismic reflection profiles, and magnetic and gravity anomalies. The detailed maps presently available for this information are proprietary, in the files of a few government agencies or academic institutions, or contained in published geological or geophysical reports. Such reports normally are regional to topical interpretive syntheses of all available data. Although most are research oriented, some emphasize such applied topics as offshore mineral resources, sea floor foundation characteristics, regional geology, and potential hazards.

Some substantial technical shortcomings remain in the available navigation systems for marine minerals exploration and exploitation. During prospecting surveys, large areas must be covered, and position accuracy must be on the order of the size of the ore deposit. Presently existing systems, including hyperbolic and satellite navigation, are usually adequate for these efforts, though for operations far from land these methods could be significantly improved. For subsequent phases of development, in which accuracies of a few meters are necessary, geodetic positioning is difficult.

Deep Ocean

The development of fully automatic systems to produce reconnaissance scale topographic, geophysical, and geological maps are needed for future manganese nodule resource assessment surveys. Existing tools, which include real time deep ocean television systems, free fall samplers, deep sea cameras, and wide beam bathymetric systems, have provided a limited capability to locate potential ore bodies; however, there is a need to increase the rate at which the assessment is accomplished.

Bathymetry determined from the sea surface by wide beam sonar transducers cannot provide realistic representations of the sea floor environments in which the manganese nodules occur. The development of a commercial version of the Navy's narrow beam bathymetric system, coupled with existing satellite and acoustic sea floor navigation technology, would enable the preparation of microtopographical charts from a small survey ship operating in the 14 to 28 kilometer/hour range. Data could be automatically processed, either on shipboard or ashore, to produce contour maps.

Although the inventory of available tools for conducting location and assessment surveys appears to be large, the tools are actually deficient in terms of providing effective and economical surveys of smaller areas for mine-site delineation. Microtopographical maps, needed for detailed resource assessment and mining equipment development, will require a further increase in capability. The technology for acquiring ocean floor data for these maps may be derived from the existing Scripps Institution's "deep tow" system which includes: (1) up-and-down-looking sonar, (2) side-looking sonar, (3) obstacle avoidance sonar, (4) 4 kHz bottom penetrator record with accurate bathymetry, (5) bottom still photographs (stereo and wide angle) and (6) low resolution slow-scan television. The deep tow vehicle is capable of working to depths of approximately 7 kilometers, and approximately 9 kilometers of cable are used with the system. Towing speed is approximately 2.7 kilometers/hour, which limits severely the rate at which the area may be surveyed, because the lateral coverage by the side-looking sonar is only approximately 370 meters for each traverse. A commercial version of this device to meet the specific needs of deep ocean mineral surveying, including the addition of real time TV and automatic shipboard contour mapping systems, would be an important contribution to the improvement in detail surveying for nodule resource assessment.

In order to conduct an assessment of deep ocean resources, the capability is required to conduct <u>in situ</u> metal analysis and evaluation. Improved side-scan and sector-scan sonar equipment is necessary, as well as improved TV systems and high speed towing techniques; automatic devices to scan a TV signal to provide a nodule census for deposits evaluation; and improved sample collection devices, operable from the surface and capable of collecting a large number of samples at known discrete locations to permit statistical determination of ore tenor and concentration.

To determine the metallic mineral potential of oceanic crust other than manganese nodules, resource research and assessment should be directed as follows:

- The processes of metal concentration in oceanic crust (metallogenesis) should be studied when such processes occur at oceanic ridges where oceanic crust is created.

- The processes of transfer of metals concentrated in oceanic crust to continents and islands should be studied where, in the general case, oceanic crust is destroyed at oceanic trenches and where, in the special case, oceanic crust is preserved by incorporation into islands and continents.

The current state-of-the-art in oceanographic instrumentation is largely suited to regional survey-type investigations. To support the detailed studies required to evaluate the metallic mineral potential of oceanic crust, a new generation of oceanographic equipment and instrumentation is needed, such as:

- Additional deep towed instrument systems, presently in prototype stage, to gather near-bottom geological, geophysical, and geochemical data efficiently.

- Instrument systems for deployment on the deepsea floor to obtain time series measurements of relevant geological, geochemical, and geophysical parameters.

- Submersibles with six kilometer depth capabilities supported by vessels with long range (5,000 kilometers) cruising capability for observations at oceanic ridges and in oceanic trenches.

- Deep sea drilling capabilities in solid rock without overlying sediment to sample for metallic mineral deposits in oceanic crusts.

Continental Margin

With the exception of new radiometric sensors and application modes for determining metals in seafloor sands, the same tools that were traditionally employed for assessment on land are still in use. New assessment tools and procedures are required if large areas of the seafloor are to be evaluated in the 10 years ahead, such as:

(1) Coring tools that will core through 25 meters of hard sand, gravel, and stiff mud.

(2) Seafloor in situ sensors that will rapidly and accurately record gold, platinum, copper, lead, zinc, chromium, titanium, iron, and barium.

(3) Electrical and self potential and resistivity survey tools for shallow sub-bottom mineral deposits in salt water.

(4) Computer programs that will permit early recognition of subtle metals dispersal or enhancement through a heavy background of "data noise."

(5) Analytical procedures for determining noble metals in concentrations below 1.0 parts per million.

(6) the development of integrated systems approaches for specific application to marine minerals.

Surface current charts indicate monthly mean direction and speed of surface currents and may also include mean frequencies of direction and speed of currents (i.e., current roses).

For utilization in marine minerals resource assessment and mining operations, an increase in detail for the continental shelf area is needed. An additional need is for increased accuracy.

Genesis of Marine Minerals Deposits

Extensive research on the generation and regeneration of OCS deposits that are influenced by the marine environment would enhance the development of a meaningful assessment survey program.

Chief among such deposits is the marine placer, either the high-energy, winnowing/concentrating placer or the less understood, low-energy placer. In the former, swift currents and waves act to concentrate coarse particles of gold, platinum, cassiterite (tin), and other heavy minerals. In the latter, the major influence is the chemical and electrical properties of the ultra-fine (2 to 20 micron) metal-bearing particles and a quiet depositional site. Recent Sea Grant sponsored research has suggested that clues to the origin of low-energy placers and some fine-grained, high-energy placers are likely to be found in further study of geo-catalysis, organic composition of the placer deposit, interstitial water, fine particle geometry, and specific surface area. These are, in turn, related to processes operating in the provenance area, in the transport conduit, and in the basin of deposition. Clearly, an understanding of the processes by which placers are formed is needed in order to explore for them and to estimate natural regenerative effects.

There are other reasons to pursue genesis research. These include: (1) a need to understand the nature of the deposit in order to design new mining and beneficiation systems, including hydrometallurgical recovery systems; (2) a need to understand the possible environmental problems unique to different types of placers; and (3) a need for deposit data that can be used in designing new mining and exploration tools, such as new geochemical sensors, new geophysical systems, and data-handling software.

MINING EQUIPMENT

Deep Ocean

At the present time, two methods for manganese nodule mining for which data are available are under development and have been tested in the deep sea. One, the continuous-line bucket (CLB) dredge, consists of a loop of synthetic rope which extends from a surface ship to the ocean floor. Open mesh metal dredge buckets are attached to the line every 20 to 50 meters. A traction machine on the ship moves the line so that empty buckets descend on one limb of the loop, contact the ocean floor collecting nodules, and are hauled up on the ascending limb of the loop to discharge their content of nodules on shipboard. As the ship (and the dredge system) moves slowly, each successive bucket is exposed to a fresh strip of the ocean floor to collect nodules.

A second method under development for nodule mining is the airlift hydraulic (AL) system. This system employs a ship fitted-out with equipment similar to that of a deep-sea drilling vessel. A pipe extends from the ship to sea-floor, at the bottom of which is a truss assembly and a dredge head fitted with jets, harrow blades, and rake-like appendages optimized for gathering nodules of a prescribed size. Transport of nodules from the seafloor to the mining vessel through the pipe is achieved by entrainment in a high-velocity water flow. The flow is maintained by injection of high-pressure air at locations along the pipe reducing the density of the fluid inside the pipe relative to the density in the surrounding water column.

A third method, the use of large, electrically-driven pumps to raise nodules, is being investigated as an alternative to the airlift.

Consolidated phosphorite deposits and possible nodule crusts that may contain high amounts of precious metals, such as those reported in the vicinity of the Hawaiian Islands and the Mid-Atlantic Ridge, and metallic sulfide deposits in deep ocean crusts may be of interest in the future. No real advancement has been made to develop mining devices capable of recovering these deposits. Cutter head and impact devices may be readily adaptable to this application, but no development work has taken place to date.

Continental Margin

There are two main systems of suction dredging applicable to the United States continental shelf; one is the trailing suction hopper dredge, and the second is the modified cutterhead pipeline dredge. The hydraulic suction dredge is similar to the cutterhead dredge but with several modifications. The modifications include a different type of suction head and grating or sorting equipment installed on the dredge. The material that is not utilized is dumpled directly overboard, usually through a submerged discharge line.

Dredgers for sand and gravel have not been extensively developed in this country because the sand and gravel dredging recovery operations are quite limited. However, the technology for sand and gravel dredging is highly developed in the United Kingdom and the Netherlands. As a result, modern equipment is available overseas to recover sand and gravel efficiently from the continental shelf.

The clam dredge for mining shell is used by the Japanese because it is economic for the numerous low-volume, close-to-shore operations. However, some coastal erosion problems were apparently caused by mining too close to shore and the industry is looking for possibilities of developing equipment employing hydraulic suction dredging techniques.

After dredging the sand, gravel, and shell, some processing is required for separation. Vibrating screens can be installed on sand and gravel dredgers separating the sand and gravel in the desired percentages. Since the market requires a ratio of sand to gravel of 40:60, the remaining gravel or sand fraction may be rejected back to the system. An alternative to separating sand and gravel aboard a dredge is transporting it to a shore-based facility where it can be separated. The facility may include crushing to reduce the gravel to desired sizes, as well as washing, screening, and classifying. Clay, salt, and shells may be washed out by the shoreline processing techniques, which then separate the material into a variety of sizes, as required by the market.

The deep ocean mining industry consists of a few multinational consortia that are making large investments available for research and development. The present shallow water sand, gravel, and shell dredging industry generally operates in protected, inshore waters and consists of geographically scattered small companies having limited capability for major development work. Outside capital or government support would be required to develop economically sound and environmentally safe equipment for use in offshore mining. No major technical breakthroughs are required. However, the work should be started on development of engineering concepts for new dredges for sand, gravel, and shell that could 1) endure the offshore ocean environment and 2) provide economic advantages to the overall industry. The dredges, which can be either hopper or plain suction type, should be efficient, being able to work in significant wave heights up to 2 meters, and designed to minimize the environmental impact through a reduction of turbidity at suction, by the use of underwater pipelines and underwater discharge. Concepts such as catamaran hulls, semi-submersible bodies, a pump at the end of the ladder, a hood over the suction head, and the ladder movement separated from the hull movement should be evaluated.

Today's working dredges should be modified to increase their seaworthiness, possibly operating up to 1.5 to 2 meter significant waves and to reduce or minimize the environmental impact. Sorting and grading plants on the dredge itself can be designed, using existing technology for plants built on land. The possibility of using an auxilliary vessel where the materials can be sorted and graded should also be considered for achieving greater economy.

Structural Loads Induced by the Environment

The information required by the ocean mining equipment designer consists of two major parts: 1) environmental conditions -- a description of the magnitude of various environmental phenomena and their probabilities of occurrence -- and 2) environmental effects -- a description of loadings induced by the environment on the various parts of the vessel and its equipment. The methods presently used for developing forecasts of expected environmental conditions are 1) through extrapolation of existing data and 2) the use of available historical meteorology data as the basis for developing predictive data on the magnitude and currents of given wave characteristics.

Wave spectra methods have also been utilized, and the various methods and coefficients are frequently revised to take account of more recent field data. The present methods to describe wave characteristics may be summarized as follows: statistical and historical data are first developed to provide the designer with the specification of wave characteristics to be used in structural design (design wave characteristics). These include wave height, wave period, wave spectrum, and frequency of occurrence. After the initial values are developed, an economic study is made of the given vessel and dredging system, and a decision is based on both the loading induced by the environment and the environmental conditions, with due consideration given to the number of days that the given vessel should operate at sea, and the expected life of the vessel and equipment. Once the design wave characteristics have been adopted, force estimates are developed, using available theories and estimates connecting wave characteristics with induced forces. Neither the theories nor the estimates are completely agreed upon, and a great deal of judgment is required of the designer in using a theory or estimate that takes relevant particulars into account.

While the wave forces are generally important, wave dynamic excitation and interaction forces are of primary concern in the design of the dredging vessel and floating or submerged pipelines. Of importance in the dynamic response loading category are the dynamic interaction forces developed between the pipeline, the moving vessel, the draghead, and the seabed, as well as the interaction between waves and floating or submerged pipeline resting on the bottom. The oceangraphic data and the desired degree of precision required to estimate forces are:

Waves

Regular Wave Data

a) Design wave height, ± 10%

b) Maximum wave heights, ± 15%

c) Wave length, or period, particle velocities and acceleration, ± 10%

Irregular Wave Data

a) Short-term Description:

Distribution of Wave Heights

Wave Periods, and Energy Content as a Function of Sea State and Directional Spectra, ± 15%,

b) Long-term Description:

Variation of Sea States or Wave Spectra with Time Distribution of Wave Heights and Periods,

Recurrence Interval of Severe Storms and Hurricanes, and Distribution of Extremes, ± 10%.

Wave Determination of Hindcasting and Forecasting

a) Surface wave generation--hindcasting and forecasting, ± 15%,

b) Shallow water sea spectra, as function of wind speed, ± 10%,

c) Directional spectra for developing, fully arisen, and decaying seas, ± 15%,

d) Modification of deep water wave spectra due to shoaling, refraction, reflection, diffraction, current, and interaction of opposing and following wind and waves, ± 10%.

Additional Information Required to Determine Wave Forces for a Given Environmental Condition:

a) Inertial coefficients for vessels,

b) Pipelines and suction heads,

c) Drag coefficients--Reynolds number relationship,

d) Added mass for various bodies,

e) Vertical distribution of wave forces,

f) Vortex shedding,

g) Slamming effect on objects which are intermittently in contact with water,

h) Breaking wave effects,

i) Effects of reflection and diffraction on the vessel.

Currents

Long-term information is generally not available on ocean currents; however, physical data obtained may be used in predicting the severity of environmental loads caused by currents in some cases. Data are also lacking for the shallow water areas where most of the sand, gravel, and shell dredging operations will be conducted.

Forces due to currents are of primary importance to the mooring of a dredger, and to connections between the dredger and the pipeline, to floating and submerged pipelines, and suction pipe. The desired elements and degree of precision are described below:

Regular Current Data

a) Type of current, whether due to wind-driven conditions, tidal or storm-surge current, turbidity current, longshore currents, density (including turbidity) currents, variability with time, and depth, $\pm$ 10%,

b) Magnitudes of currents, decay of current distribution with depth, magnitudes of both horizontal and vertical currents at the site, $\pm$ 10%, shallow water effects on current profile, $\pm$ 10%.

Additional Information Required to Determine Current Forces:

a) Estimates of drag coefficient,

b) Inertia and lift coefficients, and

c) Vortex shedding effects.

Loads Induced by Wind

Wind loadings are of primary significance to the floating dredger and in conjunction with the current forces, the winds provide additional forces on the mooring system. The following information is desired:

Regular Wind Data

a) Wind properties

Wind speed as the function of elevation above sea level, ± 5%;

Wind direction;

Pressure gradient;

Gust factors.

b) Wind statistics:

Distribution of wind speed at the site;

Distribution of extreme wind speeds and return period of hurricanes and tornadoes.

c) Wind forces:

Drag and lift coefficient for differently-shaped vessels and vessel superstructures;

Dynamic excitation due to gusts and unsteady wind forces;

Oscillatory forces due to vortex shedding.

General Comments

The water-structure interaction and the forces developed are of importance to provide a steady dredging vessel, whether of hopper or pipeline hydraulic suction type, and may be of particular significance for a dredger connected to a floating or submerged pipeline. Fatigue forces due to wave action are of particular significance to suction pipes and the connection between the vessel and the floating or submerged line.

In addition to the several categories described above, other environmental phenomena may have some effect on the operation and design of dredgers operating offshore. These would include such phenomena as fog frequency and visibility restrictions and variation in air and sea temperature.

Continued research and development is necessary to improve forecasting methods for site specific wave (with wave height, and period forecast) and weather conditions on the continental shelf and in the coastal waters. These forecasts should take into account that sea conditions propagated from distant storms often cause local problems for the offshore operator of mining equipment.

Attention might also be paid to the continuing development of deployable breakwaters for the control of waves at a mining site. Such breakwaters could increase mining productivity and conceivably alleviate the need for all but major storm forecasting.

A field measurement program is necessary to provide data on the environmental conditions and forces acting on vessels, floating and submerged pipelines, and suction lines. Such information would permit verification of present-day engineering models. This program should include field measurements of data such as wave heights and direction, current magnitudes, wind velocities, soil characteristics of seabed, as well as data on forces exerted on various components of the dredging equipment. This program would serve a short-term need and provide the basis for long-term studies, which will be particularly valuable for the future design of dredging equipment operating offshore.

CONSIDERATIONS FOR OCEAN MINING ENVIRONMENTAL STUDIES

Marine mineral deposits vary in their geological characteristics and in the habitats where they are found. The mining techniques used to extract each type of mineral deposit are unique in form and in the types of perturbations they cause. As with mineral deposits, there are significant differences in the marine communities in each region of the coastal zone, in the open ocean and in the deep sea. The environmental impact of a mining operation and the processing of the minerals will depend on the characteristics of the perturbation and how it affects the ecosystem of the region.

Manganese Nodule Mining

The following tabulation summarizes how the principal deep ocean mining systems will affect the marine environment:

Interaction	Mining System: Airlift Hydraulic (AL)	Mining System: Mechanical Lift (CLB)
(1) Scrape sea floor	X	X
(2) Benthic turbidity plume	X	X
(3) Rain of fines during ascent		X
(4) Discharge plume at surface	X	

Since nodules lie on the ocean floor, the mining technique is simply a matter of skimming off a superficial layer that is a few centimeters deep. The CLB system may penetrate the sediment to a depth of 20 centimeters but probably much less. Both the CLB and AL systems have been engineered to separate the nodules from the sediment as much as possible on the ocean floor, thereby causing the least possible disturbance of the sediment, consistent with efficient collection of nodules.

A projected 3 million ton-per-year mining operation will recover 10,000 tons of nodules per day. If the nodule concentration is 10 kilograms per square meter, then 1 square kilometer will be swept clear each day. However, considering the inefficiencies of bottom sweep and nodule pick-up, probably 2 to 3 square kilometers will be mined per day. Using a dredge head 15-meters wide, the mining ship would have to sweep a path about 100 kilometers long each day. In any projected mining operation, it is unlikely that the dredge head will directly disturb more than 50 percent of the claim area.

The dredging device in a deep ocean mining operation will leave behind a strip of disturbed sea floor which may persist for many years. If the airlift system is used, nodules that are too large for the collecting tools will remain.

The cloud of sediment stirred up in the operation will settle over a variable distance depending upon its settling properties and the bottom current characteristics. Silt size particles may be expected to settle out within a few kilometers while the clay size particles may be transported greater distances before settling. There may be an alteration of bottom water chemistry: bottom waters may retain in solution compounds leached out of the sediment or gained from the interstitial water.

The two mining systems differ in their potential effects on the water column. In the AL system, the nodules and associated seafloor materials are delivered by pipe to the mining ship and make no contact with surrounding sea water. The bucket dredges used in the CLB system are expected to add to the turbidity of the ocean water column as the sediment they contain washes out during ascent to the surface. This effect is probably confined to the deeper ocean layers since the buckets have been observed to arrive at the surface relatively clean and free of sediment.

The use of an airlift mining system will result in a surface discharge of nutrient-rich bottom water containing suspended sediment and fine particulates of manganese nodules.

The results of such a discharge in the surface waters reportedly may have the following effects:

- the increase of dissolved nutrients, and
- the decrease of the depth of the light-penetration through the normal euphotic zone due to turbid discharge.

Alternative Methods of Manganese Nodules Processing

The processing methods to recover metals from manganese nodules will create tailings. Several alternative methods might be considered for processing nodules and disposing the tailings.

Although nodule processing is most likely to occur on land, in order to avoid the costs of transporting wet nodules hundreds or thousands of miles, processing them at sea has been considered. If this were done, transportation would involve carrying the chemical and power supplies to the mining site and the extracted metal species back to the mainland ports. The nodule residue or tailings would simply be pumped overboard along with residual chemicals from the processing operations. Because of the complexities of the process selected for metal recovery, the operation may well have to be landbased. If the disposal of tailings on land at the processing site were a problem, consideration might be given to taking the tailings back to sea and dumping them, possibly at the original mining site.

Deep sea manganese nodules are a unique kind of mineral resource and, because of their complexity, extraction processes will have to be tailored to conform to their characteristics. A recent report of the National Materials Advisory Board's Panel on Manganese Recovery Technology extensively describe two promising processes.[15] Manganese nodules are not mineralized--i.e., the desired metals appear to be distributed as minor elements through the various phases constituting the nodules. Thus, nodules cannot be broken apart and separated into constituent minerals by such beneficiation techniques as flotation and magnetic separation. They can only be processed by chemical methods, such as leaching or smelting. One of the outstanding characteristics of manganese nodules is their high water content, which is tenaciously held, even at high temperatures. Because of this high water content, such extraction processes as roasting and smelting require excessive energy and may be less advantageous.

The usual classification of the nodule processing operation involves three-metal recovery plants and four-metal recovery plants. The so-called three-metal scheme is based on the recovery of nickel, copper, and cobalt (1.3 percent, 1.1 percent and 0.25 percent, respectively). The so-called four-metal scheme would involve the recovery of the foregoing three metals plus the recovery of the manganese content (30 percent) of the nodules. Actually, in all of these schemes, the molybdenum content of the nodules (0.05 percent) would also be extracted.

At the present time, extractive metallurgy technology indicates that the potential processes might involve any one or a combination of the following:

For three-metal plants:

(1) Sulfuric acid leach.

(2) High-temperature sulfuric acid leach.

(3) Ammonia/ammonium carbonate reduction leach.

(4) High-temperature/high-pressure ammonia/ammonium carbonate leach.

For four-metal plants:

(1) Smelting, followed by leaching.

(2) Hydrogen chloride reduction-leach.

(3) Chlorination-leach.

(4) Sulfation roast-leach/sulfurous acid leach.

Such processes as the ammonia/ammonium carbonate reduction leach and the high-temperature sulfuric acid leach have been used industrially in the processing of laterites. Smelting processes have been widely used in extractive metallurgy. Chlorination methods have not been used extensively in the raw materials processing industry.

Except for smelting and the low temperature, sulfuric acid leach process, which is characterized by high acid consumption, the tailings are comprised of fairly fine particles. In the case of three-product processes, almost all of the manganese mineral content of nodules would end up in the tailings, and thus essentially all of the nodule material would have to be disposed of, or impounded. A principal consideration for retaining the three-product tailings on land would be to recover their manganese content later.

In the case of four-product processes, nearly all of the desired metal values and half the mineral weight would be recovered. There would be no economic objective in retaining such tailings.

Disposal of tailings at sea would involve pumping particles that range in size from about 1 millimeter down to 1 nanometer into the ocean. Because the tailings would be moist, the entrained liquid would also contain unknown amounts of dissolved metals. Disposal at sea would involve laying down a layer of fine nodule material with only most of the copper and nickel having been extracted. Disposal on land or on shore would generally involve impounding large amounts of the same kind of material, at or near the edge of the ocean.

Environmental Effects of Continental Margin Minerals Processing

Because sand, gravel, shell, and heavy metals placer deposits are generally found in distinct, and sometimes localized deposits in shallow to intermediate water and their mining will be concentrated in relatively small areas, their exploitation could alter the topography of the area. In some cases the changes will be sufficient to alter the currents and rates of sediment transport in the area surrounding the mine site.

Removal of sand, gravel, shell, and placer deposits will generally leave depressions in the sea bottom of 1 to (in some cases) 10 meters deep. Because of the tendency of materials to attain the natural angle of repose underwater and the possibility of underwater slides according to a slip-circle analysis, the actual area affected by mining will be greater than the deposit area. Evaluation of the long-term effect of mining on the geology of an area is critical because it is the key to understanding the long-term environmental impact of shallow-water dredging. The benthic organisms will be removed from the immediate area dredged. However, since slides and the alteration of the side slopes of depressions will carry with them benthic populations from the surrounding areas, re-population of the area may be fairly rapid after mining activities are completed.

The physical and chemical properties of the deposit must be known prior to mining operations to identify the types of fine material that will be suspended during mining and whether or not any potentially toxic materials might be released. Almost all of the conventional dredging methods will produce a turbidity cloud of varying magnitude which may release heavy metals to the water column. Nutrients will also be released to the water column.

Mining of phosphorites and sulfates will also produce depressions similar to the sand and gravel mining, however, the dredging operations will be conducted in deeper (intermediate) water and the environmental impact will be less either because of a greater dispersion rate of the turbidity cloud or the lower concentration of released chemicals into the water column. There is likely to be some release of chemicals into the water column from sulfate mining.

Post-mining modifications to the mining site require consideration of the natural processes which vary from location to location. In some areas, there is a considerable movement of sediment and poor slope stability and in other areas there may be very little sediment transport. In the former case, the depressions caused by mining will be filled up in a relatively short time.

It is generally less expensive to separate tailings from sand, gravel, shell, and placers at the point of their recovery. This means that a fairly large volume of tailings will be returned to the seabed on a continuous or semi-continuous basis. In the case of sand mining, silt and gravel may be present in the tailings; in the case of gravel, sand will be returned to the seabed as tailings. For example, a modern trailing hopper dredge especially designed for gravel mining may return up to 40 percent of solids dredged (the tailing material in this case) to the seabed. The dredged material passes through the screens separating gravel from sand and water on a continuous basis. Any water collecting in the hoppers is pumped overboard to assure delivery of dry gravel to the customer.

Large amounts of silt and clay are returned to the sea bottom in shell dredging operations. Since they are generally in shallow water (three to ten meters) and the Gulf of Mexico surface sediments are quite fine, the environmental impact is generally due to the turbidity generated by dredging operations. Modern shell dredgers discharge tailings under water to reduce turbidity. No attempt has been made to modify the drag head of the shell dredger to reduce turbidity generated. Silt curtains may be used in shell dredging but this practice is at present limited to channel maintenance dredging to protect live oyster beds.

In placer mining, physical screening and hydrocycloning also separates desirable material from tailings which are returned to the seabed. In mining phosphorites, sulphates and barites, in general, only sea water is separated from the ore. Thus, disposal of tailings is minimal.

The processing plant for sand, gravel, shell, and placer mining will generally be in a harbor area on land. Only a mechanical screening process may be required for sand and gravel, thus no tailings will be generated. In the case of placer mining, some tailings will result, and will be disposed of on land or at sea.

The beneficiation plant for phosphorites, sulphates, and barites may be at sea. The tailings would either be returned to the sea or disposed of on land. Tailings returned to sea may physically affect the benthic organisms or affect the water column through the release of chemicals or heavy metals. Little research has been conducted on the rates of release of chemicals to the water column as a function of tailings size, concentration, and depth of water.

Marine Biological Communities in Relation to Potential Environmental Issues

All marine biological communities are heterogeneous on some scale and most populations undergo seasonal, annual or long-term fluctuations, oscillations, or migrations. Aside from historical data on commercially important species, very little information is available on the dynamics of marine organisms.

Marine biological communities are regularly affected by natural perturbations (e.g., storms, predation, blooms of toxic organisms). Succession from systems dominated by short-lived pioneer species to mature communities characterized by long-lived competitively dominant species does occur. Early successional communities may have a higher productivity than later successional stages, although the suitability of different successional stage communities as feeding grounds for commercially valuable finfish is unknown.

Succession in marine communities may be studied using small scale perturbations and can be done on a limited scale. In some regions, the sites of previous mining operations may provide a historical record of potential long-range impacts on marine biological communities. Long-term autecological studies of selected communities are necessary to describe the population dynamics of the component species and the variability and oscillations that naturally occur. Carefully done environmental impact studies of marine operations may provide means for doing such long-term population dynamics studies.

Species lists, cluster analyses, and diversity indices provide very limited information about how communities are organized and the processes that structure them. In general, the physical and chemical properties (sediment properties, currents, depth) of an area determine the species composition of a community, while biological processes (competition and predation) structure it. It is necessary to know the linkages within a system in order to predict how and why perturbation of one component will influence other parts. An understanding of the linkages will require experimental manipulations in the field and controlled laboratory experiments, as well as modified sampling and analysis systems. Many of these studies can be done by independent investigators concentrating on a single process or link.

While many gaps remain, the knowledge of marine ecosystems is advancing rapidly. It should be possible to increase greatly the predictive capability of environmental studies by focusing research efforts on those components of the environment likely to be affected, given the type of perturbation and the properties of a specific environment. It is critical that an experimental approach be utilized in which specific questions or hypotheses are generated that can be tested by appropriate studies.

The experimental approach could be tested and compared with the standard environmental impact statement (EIS) format in a government supported study similar to the Deep Ocean Mining Environmental Studies Project (DOMES), which is designed to study the environmental effects of a specific type of marine mining operation (manganese nodules).[16]

THE CONCEPTUAL FRAMEWORK FOR THE ENVIRONMENTAL IMPACT STATEMENT

The objective of the environmental impact statement (EIS) is to provide information that will illuminate the possible consequences of decisions for decision-makers in government and the private sector. As applied to marine mining, it would help to measure the values of the resource recovered against the costs to the environment. The costs should be expressed in terms of direct or indirect effects on society and include various tradeoffs.

As far as possible, questions of comparative costs should be decided in advance of commitments, so that decisions may remain stable and investment climates reasonably predictable. Problems should be approached by understanding the nature of the system and the result of mining-induced changes. Unguided data collection should be avoided.

Understanding the nature of the system and the effects of mining can be achieved by first examining what is known about the system and what is believed to be true about it. Short-term and future effects may have to be examined differently, depending upon whether or not the effects are lasting or transitory. Similarly near-in and far-away effects may have different consequences and, thus, have to be considered explicitly. But no matter how complex the system, one can hypothesize how it works, what is important and what is unimportant in changing it. Data-taking enterprises and experiments can then be designed to test these hypotheses and attempts made to prove or disprove them. The most striking outcome of the panel's workshop in January 1977 was the decisive consensus that enough is now known about the structure of relevant marine biological communities and their behavior to engage successfully in such hypothesis-testing programs to resolve the uncertainties significant for the preparation of EIS.

Such tests may involve laboratory experiments, field experiments, carefully designed surveys, and pilot mining experiments with observation. Design of the tests may not be uniform in space or time, but may concentrate on catastrophic events or the places that are important to understanding the system processes. The hypotheses are then revised and new tests are devised to test the new hypotheses. Thus, the significance of particular mining-induced effects can be determined within a given framework.

When properly done in the framework of a defined problem, this process can provide estimates of what is happening at other places and times (within the domain of the problem) and can be used to quantify the probable results of mining-induced changes. It is important to realize that at best one can only state the probabilities of future events and consequences. Even though they may be desired for ease in regulation or in public communication, precise deterministic numbers are not in general possible.

This hypothesis-data-taking-hypothesis loop should be examined in relation to the problem so that the resulting conclusions are relevant. When properly done, this process is an economic effort and, in the long run, less costly than less well designed data taking approaches.

Of course, each EIS needs to be evaluated separately, including the nature of the mining and process technologies to be used. For each case, a group should be established, including scientists from government, industry, and education, the technologists who understand the potential mining systems and their use, and those who understand the basis on which regulatory and investment decisions are made. This group could operate in a mode of design theory and experiment, rather than as adversaries (although a well selected group will have plenty of controversy to consider in developing the design). Some or all members of this group should be involved not only in the theory and design of experiments but also in carrying out further steps, including preparation of the environmental impact statement. This process can be controlled, where necessary, by openness and the results submitted to independent review.

The environmental decision process is far too important to let it rest on intuitive data taking schemes. The information gathering process must lead to understanding through theoretical framework and therefore must be designed.

GOVERNMENT SERVICES

The sponsorship of research and development by the federal government varies from one industry to another and is largely dependent upon present and future national needs. To a major extent, technological research in the federal government, with respect to industry, relates to resource management, human safety, environmental protection, and national security matters.

The mining technology research presently being supported by the Bureau of Mines of the Department of the Interior falls into three basic areas: 1) mining health and safety research, 2) advancing mining technology, and 3) resource conservation and environmental protection. The FY 76 budget was about $110 million, the breakdown of which is shown in Table II:

	FY 76	Est. FY 77
	($ millions)	
Health and Safety Research		
Coal Mining Health Research	3.90	4.08
Coal Mining Safety Research	25.25	25.53
Metal and Nonmetal Health and Safety Research	5.62	5.76
Advancing Mining Technology		
Coal Mining	56.01	59.96
Oil Shale Mining	5.62	5.65
Metal and Nonmetal Mining	5.31	5.50
Explosives Research	0.64	0.66
Environmental Control Demonstrations		
Mined Land Investigations and Demonstrations	7.29	3.85
Fire Control in Coal Deposits	.24	.24
Total	109.88	111.23

Source: <u>Mining Technology Research</u>, Bureau of Mines, U.S. Departmnet of Interior, 1976.

Similar government activity directly related to marine mining technology may be appropriate as the ocean mining industry grows. For example, some foreign governments are now supporting or planning to support research into multiphase flow that may be encountered in vertical or horizontal pipes, stability of multiphase cargoes in ore carriers, and improvement in dredge head design. These examples are not necessarily appropriate to the U.S. industry but serve to indicate the nature of research that may be considered in the future.

The discussion which follows details the additional important activities that are potential candidates for government involvement now.

Government Environmental Studies

When the government undertakes environmental studies for potential ocean mining operations, it does so on the following bases: (1) The obligation to file an environmental impact statement in regard to any "major federal action" under the National Environmental Policy Act (NEPA) and (2) any other specific environmental review requirement that may be incorporated into domestic legislation with respect to an ocean mining licensing system.

The environmental impact statement (EIS) is not required from a government agency unless a "...major federal action significantly affecting the quality of the environment" is about to be undertaken (42 USC section 4332 [c]). When such an action is contemplated by a federal agency, an EIS must be prepared, describing (a) the environmental impact of the proposed action, (b) any adverse environmental affects that cannot be avoided if the proposal is implemented, (c) alternatives to the proposed action, (d) the relationship between local short-term uses of the human environment and the maintenance and enhancement of long-term productivity, and (e) any irreversible or irretrievable commitments or resources that would be involved in the proposed activity if it is implemented.

Although government studies undertaken with respect to a particular "major federal action" will tend to assess the broad range of potential environmental impacts, it may be particularly beneficial for all such studies to conclude with a report that contains a systematic analysis of the significant and insignificant data evaluated for accuracy and relevance and setting out the relationships among the different aspects of the problem in each case. Limits of confidence in the data and uncertainties in the analysis should be identified explicitly.[17]

This would call for decision making and for addressing conclusions that will lend stability to the EIS process, and make it possible for decision makers and reviewers in courts to determine promptly whether or not a thorough study has been made.

The conventional EIS procedure does not include this particular feature. The absence of such documentation requirements have led, in some cases, to uncertainty about the thoroughness of the EIS review, and such uncertainty has provoked unnecessary litigation.

The key question, then, is whether or not additional environmental safeguards should be required by the agency assigned the oversight responsibility for ocean mining and what procedures might avoid litigation.

Although the federal NEPA laws require that all EIS's be circulated to ascertain the views of federal agencies, the complexity and breadth of ocean environmental issues suggest that it would be desirable for EIS guidelines, which are issued prior to any particular EIS review, to be broadly circulated throughout the country among private-sector and university experts in the area. The level of activity at this time in federal agencies with respect to ocean issues has not yet led to a thorough range of in-house expertise for purposes of ensuring the best possible framework of guidelines.

A specific advisory board of such outside experts might be established to make recommendations for guidelines to the administering federal agencies, as some organized procedure for review of proposed guidelines would be desirable. By following such procedures, the administering agency would be in a better position to defend the comprehensiveness of its guidelines, and the carefully drafted and reviewed guidelines will be more likely to be sustained in the event of any legal challenge.

A federal agency, in meeting NEPA obligations in an area such as ocean mining, faces a decision as to whether to issue programmatic, regional, and/or site specific EIS reports. Programmatic EIS's for ocean mining would describe and evaluate the impacts of the entire agency licensing program on all ocean environments; regional studies would cover impact in a broad area. Site specific reviews would relate only to those areas covered by a particular license application.

To the extent that most present proposals for a licensing system for the ocean mining industry contemplate the requirement that individual licenses be obtained, there is a potential for a lengthy series of environmental reviews, many of which might be duplicative. Clearly, all significant environmental issues should be resolved, whenever possible, on a "programmatic" or "regional" level. If studies and the EIS guidelines review procedure both disclosed that a number of ocean mining impacts may be assessed on a broad geographical basis, such an early review and resolution of significant environmental issues would have the benefit of allowing the industry to move forward more promptly, without unnecessary delay caused by repetitious review. While the effectiveness of such programmatic reviews has already been acknowledged by the courts under NEPA procedures, specific attention should be focused on the desirability of making such broad level decisions. This will reduce the number of reviews and also reduce the potential delay that might be incurred as a result of litigation over the decisions based on the information disclosed in the EIS.

To the extent that all potential environmental issues may not be identified prior to the issuance of a license or other entitlement by the government agency, some procedure, beyond those within the scope of NEPA, might be established for the purpose of identifying and resolving significant environmental issues that may be first disclosed subsequent to an initial licensing decision. Thus, the establishment of administrative procedures might be considered (1) for resolving any issues which may arise, and (2) for setting standards to be addressed through the procedures in determining whether such subsequently observed phenomena constitutes a significant or insignificant environmental problem.

Resource Management

The management of mineral resources, when undertaken by the government, is intended to regulate the rate of mineral recovery in order to maximize the percentage of the total deposit to be ultimately recovered. The subject was discussed by the panel and a summary of arguments pro and con is presented.

For Resource Management by Government

In recovering minerals from a deposit it becomes increasingly costly per unit to capture the resource as the effort approaches 100 percent of the deposit. Often, subsequent price increases for the resource alter the amount of the deposit that could have been economically recovered. However, it is no longer possible to remine the deposit because the first recovery operation made subsequent recovery operations prohibitively costly. The result is that less of the original deposit is recovered. The government, with a longer planning horizon and a greater concern for resource availability for future generations, is more likely to require lower rates of production and larger ultimate recovery than a miner guided only by market conditions.

Against Resource Management by Government

There is no evidence either observed or theoretically derived that indicates that government is a better predictor of future prices or that the relative value of future to present consumption, established naturally in capital markets, produces the wrong rate of discount for hard mineral recovery operations. Even if firms were guided by misinformation, the policy prescriptions offered by government on behalf of resource management, such as limited leasing periods, restricted claim size, and mandated production rate ceilings, would be counter-productive. The first two policy prescriptions actually intensify the rate of production and decrease the ultimate recovery because of the area and time limits imposed on the rights to the deposit. The third either has no effect (when ceiling rates are not constraining) or limits the flow of revenue to the miner (when ceiling rates are constraining). Effectively, the property rights to future production are eroded, thereby adding to the costs of recovery. This, in turn, reduces the number and percentage of deposits that are eventually recovered. Thus, each of the major policy prescriptions to avoid "wasteful" recovery operations, in fact, reduces the value of the deposit actually recovered below the efficient level.

Technical Services

Various types of technical services are intrinsic for resource assessment and other phases of existing and anticipated mining operations on the continental margin or in the deep ocean. The types of technical services that are discussed include (1) charting and mapping, (2) weather and sea conditions, (3) marine data and technology information exchange, and (4) navigation and positioning.

Charting and Mapping

Bathymetric maps and charts of the continental shelf and deep ocean areas are available with scales ranging from 1:50,000,000 to 1:5,000 and contour intervals from 1,000 fathoms to 1 fathom. About 90 percent of the North Atlantic and 80 percent of the North Pacific are covered by bathymetric charts ranging from 6° latitude by 10° longitude near the equator to 3 1/2° of latitude by 15° longitude at 75°N. The South Atlantic Ocean, South Pacific Ocean, Indian Ocean, Arctic Ocean, and Antarctic Seas are not yet covered by this series. Worldwide coverage is available with the General Bathymetric Chart of the Oceans at scales of 1:10,000,000 at the equator and 1:3,100,000 at 72° latitude.

Bathymetric maps at a scale of 1:1,000,000 (1 nautical mile = 0.073 inch) are available for the U.S. continental shelves (except Alaskan waters). Bathymetric maps at a scale of 1:250,000 are available for only 30 percent of the U.S. continental shelf. A scale of at least 1:62,500 is needed for preliminary offshore mining development planning. Larger scales are required for conducting detailed mining operations.

With few exceptions, existing bathymetric maps and charts are not based on systematic surveys, but, rather on sounding data obtained from "random" track lines of merchant, naval and research vessels. As to be expected, these tracks have variable position and depth accuracies. For example, a celestial fix may be obtained infrequently along some tracks, while in other cases tracks may reflect nearly hourly electronic fixes. Likewise some depth measurements are obtained from poorly adjusted fathometers; while others are from fathometers maintained in continuous optimum adjustment. These inadequacies are further compounded by worldwide lack of bathymetric coverage. Figure II shows the current status and bathymetric data collection requirements in terms of coverage and degree of data accuracy for the work ocean as compiled by the U.S. Navy's Defense Mapping Agency Hydrographic Center. The most lightly shaded areas in Figure II are where data is needed at accuracies of ± .03 nautical miles or better in location and ± 2 fathoms in depth measurement. Data of less accuracy will not, in general, add to the value of completeness of the data holdings. The darker gray areas are where data should have fix accuracies of ± 1 and ± 5 miles and sounding accuracies of ± 10 fathoms and ± 25 fathoms respectively. The darkest gray shows major shipping lanes where additional hydrographic data from ships of opportunity is not desired. The white areas in Figure II marked with arrows show where data coverage is extremely poor.

Bathymetric measurements, taken from the surface by ships equipped with sonars of contemporary beamwidth, cannot provide realistic representations of the deep ocean seafloor necessary for deep ocean mining prospecting and mine-site development.

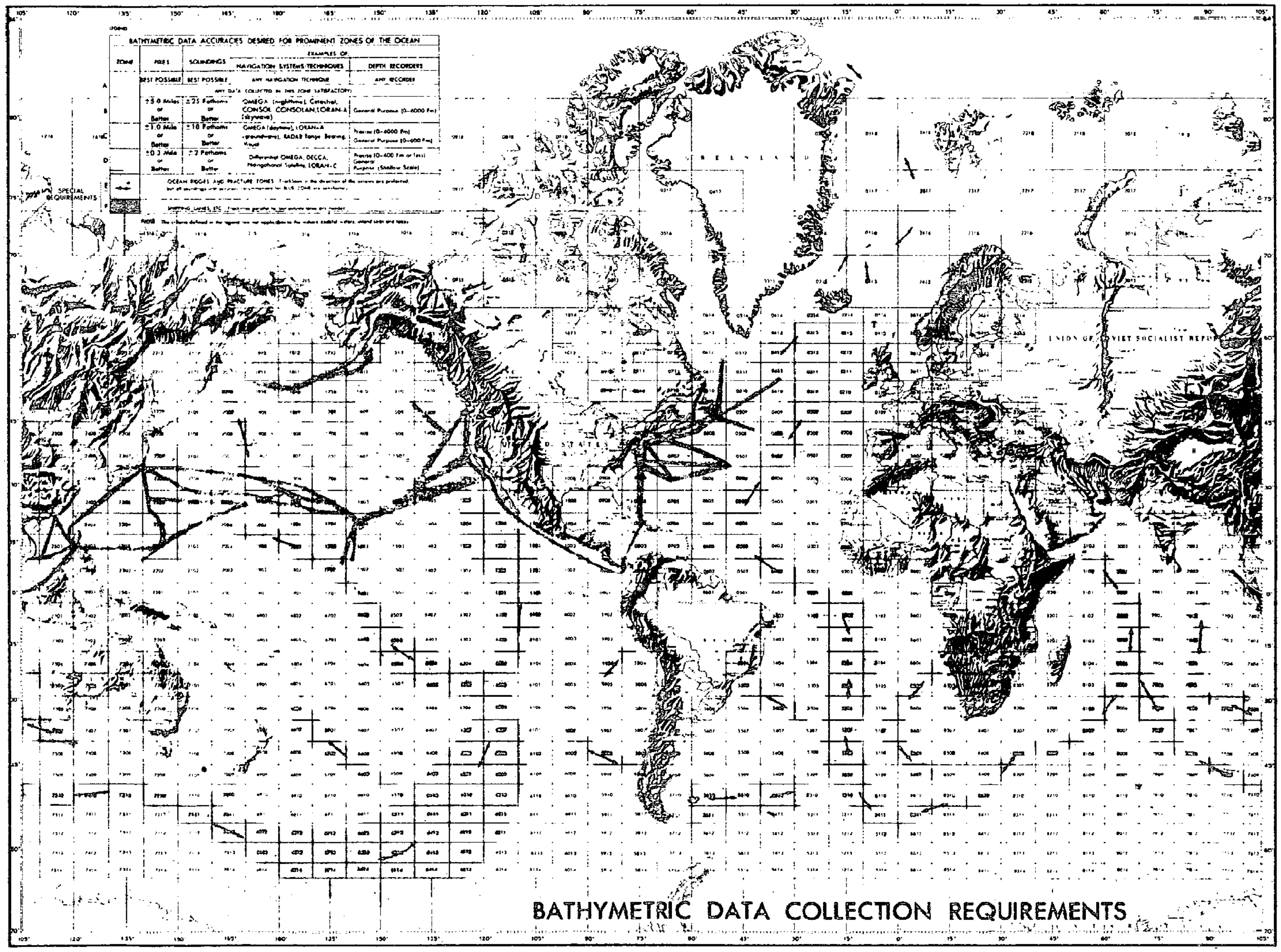
The area of coverage of available geological and geophysical reports or maps typically varies with the subject. The coastal zone and continental shelf areas have virtually no regional coverage and only a few topical reports. Another important factor which greatly restricts the value of the available information on the potential marine mineral resources on the continental shelf and in the deep ocean is the fact that the existing data were not collected as part of a systematic program of resource assessment, but rather in conjunction with marine geological research investigations having diverse objectives.

The capability to produce microtopographical maps at low-cost, rapidly, accurately and automatically is essential to the ocean mining industry and others. What is lacking is a system integration effort necessary to produce a relatively high-speed (5-14 kilometers/hour) towed instrument platform. A system with such capability could be developed from the existing Scripps Institution's "deep tow" system, described on page 16 of this report.

Weather and Sea Conditions

As in the case of any maritime-related activity, existing and proposed ocean mining operations on the continental margin and in the deep ocean require accurate, up-to-date forecasts on weather and sea conditions in order to maximize equipment utilization time, provide for the safety and protection of personnel and equipment and to develop realistic equipment design criteria. Historical summaries or atlases of weather and sea conditions also are of value for preliminary assessment of operating schedules and

FIGURE II



Source: Defense Mapping Agency Hydrographic Center, U.S. Navy environmental loads. Several types of weather and sea forecasts and atlases of interest and potential value to ocean mining operations are currently being produced on a routine basis by NOAA's National Weather Service (NWS) and the U.S. Navy's Fleet Numerical Weather Central (FNWC). A brief description of these services and products is provided in the following along with comments regarding their adequacy for ocean mining operations.

Hemispheric weather charts include surface synoptic analyses, auxiliary analyses, surface prognoses, upper air prognoses, and extended forecasts (three and five day, and 30-day outlook). Forty facsimile (FAX) charts are broadcast daily to provide guidance to Weather Service Offices with marine forecasting responsibilities. A major purpose of these charts is to provide forecasters with a broad view of weather patterns for use in predicting weather and sea state conditions; they are also useful for naval and merchant ship routing.

Wave height forecasting includes wind-wave prognoses, swell prognoses, and combined wave forecasts for 24-hour and 36-hour periods. They are issued in the form of areal charts for the North Atlantic and North Pacific Oceans, containing contour lines of forecast wave heights at three foot intervals and values of maximum wave heights centers. These charts are transmitted daily to Atlantic, Gulf of Mexico, and Pacific and Gulf of Alaska seaboard stations. NWS also produces wave charts on a hemispheric basis for use in Navy and Military Sea Transportation Service (MSTS) ship routing programs.

These wave forecasts are essential for optimum ship routing and for helping naval and merchant vessels avoid high seas. They are also used as input for coastal wave and surf forecasting. However, they are often not sufficiently localized. Nevertheless, they do provide a broad-scale picture of sea conditions to local forecasters for specific applications.

Extended range weather forecasts consist of bulletins, charts, and outlooks predicting the average weather conditions and circulation patterns for two-day to six-day periods for both coastal and oceanic areas. Longer range weather outlooks are produced which project average monthly weather quotations and circulation patterns for the northern hemisphere.

Coastal weather and wave forecasts indicate surface weather and sea conditions and upper air conditions for periods up to 36 hours after the previous synoptic time for all U.S. coastal areas out to 90 kilometers at sea. They are produced four times daily by NWS area forecast centers. Warnings are issued for expected hazardous conditions as required.

Coastal weather and wave forecasts are of major importance in the short-term planning of mining operations as adverse weather conditions can limit or prevent these activities and operations. However, a common complaint from users is that coastal forecasts are made for a large area and are not sufficiently localized to be of use for a specific coastal engineering or mining operation.

High seas weather forecasts indicate surface weather for periods up to 36 hours for oceanic areas extending from 50 miles offshore to limits defined by the World Meteorological Organization (WMO) International Convention. They are issued by three area forecast centers four times daily. Bulletins contain forecasts and warnings. These forecasts are utilized directly in navigation and routing of naval and merchant ships. Since these forecasts provide a means of predicting sea state and fetch, they are also an essential input for coastal surf condition forecasts.

NOAA's National Weather Service (Redwood City, California) and National Marine Fisheries Service (NMFS) (La Jolla, California) are currently providing "tailor-made" weather and sea analyses via FAX for the prime manganese nodule mining region in the eastern tropical Pacific bounded by 10° to 30°N and 80° to 160°W. The FAX program evolved out of the NMFS' and U.S. Navy Fleet Numerical Weather Central's (FNWC) need for environmental data from the eastern tropical Pacific area. Coupled with this, was the U.S. tropical tuna fleet's requirements for better weather information, sea-surface temperature and mixed layer depth data.

Originally, NMFS provided the entire FAX services, however, in 1974 the NWS took over the weather and sea-state chart program. The success of this program has depended heavily on the continued cooperation of a large number of tuna vessels which provide the necessary feedback of data into the system in return for the FAX charts. It should be noted that both government and industry groups who have conducted investigations in the eastern Pacific manganese nodule mining area are aware of, and have utilized the FAX charts.

Storm surge advisories are contained in bulletins describing the tidal surge expected as a result of combined storm and tidal conditions. Timely and accurate surge warnings are required in order to minimize property losses.

Local statements on storm tides are issued by Weather Bureau offices along the U.S. coast; however, forecasters are usually hampered by a lack of local tide data, adequate storm size and intensity data, and a quick and accurate technique for predicting surge.

Tropical cyclone advisories are issued as bulletins reporting the location, direction and rate of movement, and wind velocities of cyclonic systems originating in tropical zones. Advisories are issued four times daily when storms are in progress, and bulletins are issued more frequently when necessary. Advisories for storms in the western Pacific area are issued by the Navy and Air Force. Weather advisories covering tropical storm conditions in the eastern North Pacific nodule mining region are provided to mariners by NOAA's Eastern Pacific Hurricane Center located in San Francisco, California. During 1975, advisories were issued on 87 days covering 16 storms and 4 tropical depressions. Since 1966 probably all of the tropical storm activity in the various oceanic regions has been closely monitored because of the excellent picture coverage provided by weather satellites. As a matter of interest, an average of 15.2 tropical cyclones per year occurred in the eastern tropical Pacific region during the period from 1969-1975. Of these, about one-half developed into hurricanes. During 1975, six hurricanes, packing winds between 120 to 225 kilometers/hour, occurred in the eastern portion of the candidate nodule mining area between 10° to 20°N and 110° to 120°W. Depending on the fetch and duration of these winds, the significant wave heights associated with these disturbances could theoretically vary between 20 to 30 meters.

Surf forecasts describe existing and expected surf heights and periods at selected beach areas. They include warnings of hazardous conditions such as unusually high surf, rip currents, and surges, and may include beach erosion information. Forecasts cover a period up to 36 hours. Surf forecasters are presently limited by the lack of real-time monitoring of wave conditions in specific locations.

Tsunami warnings consist of bulletins which advise the public of the expected times of arrival of a seismic sea wave at various coastal locations. Normally, several sequential warnings are issued for each detected tsunami. Predicted arrival times of tsunami waves are within 2.5 percent of total travel time. A present limitation is the difficulty in accurately predicting wave height and runup, which results in unnecessary evacuations and suspension of various types of offshore activities.

Sea ice forecasts are issued as large-scale charts which cover specific areas (e.g., Baffin Bay, north coast of Alaska). They indicate the nature, extent, and concentration of sea ice cover by means of symbols and patterns on the chart. Iceberg concentrations and distributions may also be indicated. Such forecasts are transmitted by radio teletype and FAX to naval and other vessels operating in ice areas. Industrial operations are increasingly concerned with sea ice in view of the expanded development of mineral and petroleum reserves in the Arctic.

Marine climatological atlases contain historical summaries of climatic data on a monthly basis, including surface wind roses (wind speed and direction frequencies), storm track means and distributions, sea level pressure, air temperature, sea temperature, precipitation, visibility, clouds, air-sea temperature differences and dew point. Increased detail of these atlases for the continental shelf areas is required for deep water port design and operations, offshore oil and gas platform design, planning mining operations, and environmental prediction.

Wave and swell charts indicate monthly percent frequency of seas greater than 5, 8, 12, and 20 feet; monthly swell height, direction, and constancy; seasonal persistence, wave period-height and wave period-direction; and seasonal percent frequency of seas requiring speed reduction. Worldwide small scale coverage is available.

The bulk of the data in surface current charts consists of set and drift observations made by Navy and merchant ships. These observations reflect the average surface current over a distance of 100 to 800 kilometers and have a highly variable accuracy because of variations in navigation accuracy, helmsmanship, and frequency of course changes.

Ice atlases consist of maps indicating the monthly average and extreme of ice coverage, thickness and type. Also included are the mean and range of ice freezeup and breakup dates. Worldwide coverage is available only at small scales. Larger scales and increased geographic coverage, especially for continental shelf areas, is needed for planning offshore oil and mining operations, offshore and shoreline structure design, and other marine activities.

Marine Data and Technology Information Exchange

The need for an inventory of marine data holdings, samples, products, and publications related to marine mineral resources development has become increasingly evident. To the industrial user, it is important to know where to turn for the data, samples, products, and/or publications of immediate need.

Included in the foregoing are ocean engineering data which are becoming increasingly important to the ocean mining industry. Until lately there has been no need for a focal point for monitoring, evaluating, and transferring non-classified government technological developments in terms of their applicability to improving reliability and performance of commercial ocean mining. Along these lines, the need also exists for a description of the nature and availability of unique government owned or sponsored test facilities that might be utilized by the ocean mining industry. Such facilities include vessels, survey equipment, test equipment, and laboratory services. In the following discussion an overview of existing capabilities within the government that meet these needs is presented, along with comments regarding their accuracy.

Marine environmental data and information management services are currently centered within NOAA's Environmental Data Service (EDS). Data types include: physical, chemical, geological, and biological. EDS is specifically charged with acquiring and processing these data from originators and compiling them in a form useful to the general user community.

To accomplish its mission, EDS operates a number of specialized data centers and a comprehensive data and information referral system. A brief description of these follows:

- The National Climatic Center (NCC) is the custodian of U.S. weather records and the largest climatic data center in the world. It also disseminates environmental and earth resources satellite data, as well as photographs taken during NASA's SKYLAB missions. NCC houses World Data Center-A, Meteorology, and Nuclear Radiation.

- The National Oceanographic Data Center (NODC) houses the world's largest collection of oceanographic data and provides facilities for World Data Center-A, Oceanography.

The National Geophysical and Solar-Terrestrial Data Center (NGSDC) is the national center for marine geological and geophysical data management and services. NGSDC has been assigned the responsibility of acquiring, processing, archiving, and disseminating data resulting from international and national programs such as the International Decade of Ocean Exploration (IDOE), the Outer Continental Shelf Environmental Assessment Program (OCSEAP), Deep Ocean Mining Environmental Study (DOMES), and the Marine Eco-Systems Analysis program (MESA). NGSDC also archives and disseminates data for other government agencies, such as common depth point (CDP) seismic reflection data collected by the U.S. Geological Survey and digital hydrographic data collected by the National Ocean Survey.

° The Environmental Science Information Center (ESIC) disseminates environmental scientific and technical literature and information and manages or provides functional guidance for NOAA editing, publishing, and library programs.

° The Center for Experiment Design and Data Analysis (CEDDA) provides experiment design, data management, and scientific analysis support to large scale environmental field research projects, to ensure that data needs are met for both project scientists and subsequent users.

° The Environmental Data Index (ENDEX) and Oceanic and Atmospheric Scientific Information System (OASIS) provide a rapid, computerized referral to available environmental data files and published literature in the environmental sciences and marine and coastal resources respectively.

ENDEX data bases are computer-searchable interdisciplinary files of environmental data consisting of three major components: (1) descriptions of data collection efforts; (2) detailed inventories or large, commonly used files; and (3) descriptions of data files. Data catalogs from large NOAA environmental data collection projects can be identified. ENDEX data bases are updated every two years.

EDS is currently developing a multidisciplinary data base for the Outer Continental Shelf (OCS) and is the official repository for all of the data/information now being generated by the U.S. Bureau of Land Management's (BLM) Outer Continental Shelf Program. EDS also recently established a Deepwater Ports Project Office to meet the data/information requirements placed upon NOAA by the Deepwater Port (DWP) Act of 1974, which establishes procedures for the location, construction, and operation of deepwater ports off the coasts of the United States. EDS' project office reviews, evaluates, and prepares recommendations for the administrator on DWP license applications, related environmental impact statements, and adjacent coastal state status.

Ocean Engineering Technology and Data Exchange The Naval ocean engineering program is extensive not only as a result of its in-house capabilities, but also because it includes facilities and operations that directly utilize private industrial contractors and academic personnel. A good part of these informational and facility capabilities are available for industrial ocean engineering activities through the Oceanographer of the Navy. Most of the Navy's unclassified reports that are presently being submitted to the Department of Defense Documentation Center (DDC) are being made available through the National Technical Information Service (NTIS).

Because of the wide variation in types of data products used in ocean engineering, and because the ocean environmental data product needs are commonly both highly sporadic and restricted to the relatively small geographic areas for which extremely detailed data are needed, it appears that centralized ocean engineering data for a specific location is not warranted. However, there is a definite need to establish a focal point in government for monitoring and evaluating technological developments for application to improving reliability and performance of commercial ocean mining, and to provide an active mechanism for transferring this information and identifying technological gaps that may interfere with future mining efficiency and capacity to meet regulatory requirements.

In addition, scientists and engineers overseas have expressed interest in sharing and exchanging information that would lead to a more meaningful assessment of environmental change associated with ocean mining. An international research program that would include, but go beyond, present information exchanges and that would have as its objective the creation of new knowledge pertinent to environmental change, its measurement and its assessment in terms of societal needs and/or values could be of great value. Clearly, the fledgling United States offshore sand and gravel mining industry would stand to benefit from such an exchange.

Navigation and Positioning

With a few exceptions, commercially available navigation aids are presently adequate for the prospecting, exploration, and exploitation phases of marine mining. In many relatively remote sites, however, the ultimate limiting factor is the uncertainty associated with establishing an absolute position.

Prospecting for marine mineral deposits usually involves relatively long-range, permanently established, positioning systems such as those used by most commercial vessels. Hyperbolic systems and satellite systems (Table III) are the primary navigation tools in most cases. For most continental shelf deposits, the hyperbolic systems are satisfactory, providing continuous access to position information with precisions on the order of a nautical mile. In coastal waters, radar triangulation is frequently used to obtain more precise information, and satellite fixes are generally also incorporated into the track record when they are available.

Satellite navigation is currently the only effective method for obtaining precise fixes in the deep ocean manganese nodule regions. The most serious limitation to this method of navigation is the fact that good fixes can be obtained approximately once every hour, and the ship's position can only be estimated by dead reckoning between fixes. This limitation reduces the practical precision of satellite navigation to that of the dead reckoning method. Significant improvement would result if more navigation satellites were operable or if high quality inertial guidance systems were available commercially to improve the accuracy of the dead reckoning system.

The most promising of the new satellite locating fixing systems is the Navigation System with Timing and Ranging (NAVSTAR) global positioning system (GPS) which is expected to be fully operational by the mid 1980's. When operational, this system will involve 24 satellites, six of which will be in view at all times. The result will be to provide a continuous location determination in three dimensions with an accuracy of five to ten meters. Ultimately, it is expected that the system will provide ± 1.0 meter accuracy for fixed structures and five to seven meter accuracy for shipboard use. This system appears to satisfy practically all offshore surface requirements and many of the nearshore needs as well.

TABLE III

ELECTRONIC POSITIONING SYSTEMS*

NAME	RANGE	ACCURACY
Satellite Systems		50
MX-702 h.p.		50.0 m
Update Geo Navigator	Global	60.0 m
7007 AB		0.18 km
Hyperbolic Systems (Long Range)		
Omega		
Omega-1	Global: each station	1.8-3.7 km abs
Omega RO10 & RO11	covers 9200 km	
Omega OR-100A		
Loran-A	1300 km (day)	
	2600 km (night)	3.7 km
Loran-C	2200 km	75-450.0 m
Hyperbolic Systems (Medium Range)		
Decca Navigator	460 km	5-3.7 km
Lorac-A	370 km	5-120.0 m
Lorac-B	370 km	5-120.0 m
Decca Survey	370 km	7.5-90.0 m
Hi-Fix (2 range or		1.1 m (hyp.)
hyperbolic)	46-370 km	.76 m (2-range)
Rana F & G	92-140 km	10-23.0 m
Toron	740 km	1-30.0 m
Azimuthal		
Consol	1300 km	±11.0 km
Sextent		
Various	1.8-37 km	
Radar Ranging (Example)		
Model 436	128 km	±1.5 m
Ranging Systems		
LAMDA	270-740 km	5-12.0 m (day)
Hydrodist	46 km	1.5-30.0 m
Shoran	22-74 km	9-15.0 m
EPI	22-740 km	40-460.0 m
Raydist DR-S	460 km (day)	
	275 km (night)	"few meters"
Autotape DM-40	115 km	$\left(50 + \frac{\text{range}}{100,000}\right)$ cm
Acoustic Systems	Depth Limitation	Accuracy
MRQ-2015A Doppler Sonar	.3-180 m	0.2% range-120.0 m
		0.5% 120-180.0 m
		distance travelled
APRS	to 900 m depth	0.5-1% depth
Deep Water Fixing & Command Retrieval	6000 m	
Underwater Location Equipment	to 365 m depth	±15 m radius from beacon
TIP	to 6000 m depth	
Acoustic Position Measurement (APMS)	15-6000 m depth	0.25-1% depth
Navtruk 435	180 m depth	0.5% distance

*Adapted from: J.R. Moore and M.J. Cruickshank, "Identification of Technologic Gaps in Exploration of Marine Ferromanganese Deposits," Sea Grant Advisory Report No. 4, University of Wisconsin.

Exploration and subsequent mine site preparation require more precise navigation than that available from present satellite and hyperbolic systems. Detailed delineation of an ore deposit usually requires position accuracies on the order of a few meters. Currently, there is no obvious way to achieve the accuracy, density, and permanent marking of points at sea as is required. The seabed is the only place to put truly permanent markers, and the gap between the sea surface and the seafloor in waters more than a few tens of meters is hard to bridge.

In view of these problems, activities in these areas have often gone to a system of relative, rather than absolute, positioning. If one is concerned with reasonably good accuracy within a rather small area, it is possible to establish and mark a local datum. In coastal waters this can be accomplished with surface ranging systems (Table III). In the deep ocean, the same function is served by the commercially available, acoustically operated, bottom transponders such as the American Machine and Foundry (AMF) "ATNAV" system. It should be emphasized that these systems per se, are not tied to a worldwide geodetic system and thus provide only local relative position data. Nevertheless, they do meet the requirements for local ore deposits where precise latitude and longitude determinations are not required. However, in order to establish legal mining site boundaries, precisely known reference points will have to be defined.

CONCLUSIONS AND RECOMMENDATIONS

The panel concluded that, with certain exceptions, the technology for ocean mining operations is now well developed. What remains critical to improving the prospects for ocean mining are capabilities for more accurate resource assessment and location as well as environmental understanding and monitoring.

The panel has observed that the government's participation may be necessary to promote the orderly and expeditious development of mining operations in the ocean, to ensure, among many matters, that the recovery activities do not impose significant harm to the ocean or coastal environments. The government may appropriately provide technical services such as charting and mapping, weather forecasting, and data for environmental predictions. The government may also have a role in supporting and encouraging basic research. Areas for study such as mineral genesis, mineral processing in an environmentally safe manner, determination of the thickness and physical properties of unconsolidated sediments in shelf environments, and equipment development for the more crowded, intensively used areas of shallow water mining are suggested.

Criteria for Panel Recommendations

The panel's recommendations were based on the following criteria:

1. The recommended action, if carried out properly, would be likely to encourage the development of technologies, environmental methodologies, and/or services that enhance the capability, and

2. The recommendation, if implemented properly, would be likely to meet environmental concerns with respect to ocean mining.

The order in which the recommendations appear represent the panel's priorities of importance:

RECOMMENDATION 1

The panel recommends that the methodology for environmental impact studies of marine mining should be redirected toward the testing of theoretical constructs and scientific hypotheses associated with ecological processes at the mining site that are affected by mining activities as distinct from non-specific data gathering efforts.

The panel recommends that studies relating to specific regions and mining technologies be undertaken in the following areas:

1. Development of improved understanding of biota community structure and organization, population dynamics, succession, and natural fluctuations particular to each specific mining-affected environment;

2. Identification of key linkages between different components of affected ecosystems which may be used as indicators of significant change (e.g., spawning grounds and foraging areas of important and commercial species);

3. The dynamic response to mining-induced perturbations of affected ecosystems, especially,

   -- resuspension of bottom sediments and associated chemicals on biota,

   -- succession following mechanical disturbance of benthic organisms, and

   -- modifications of regionally significant nutrient cycles.

The panel recommends that the development of such a methodology is the responsibility of relevant federal agencies. In developing this methodology, the government should use the expertise of academic and research institutions and the ocean mining industry.

RECOMMENDATION 2

The panel recommends that the following procedures be observed by the government to incorporate studies into the EIS process:

1. The final report of all government studies in marine (ocean) mining should separate significant environmental issues from insignificant ones;

2. All draft EIS guidelines should be circulated among specialists in the appropriate disciplines;

3. The EIS process should identify and resolve significant environmental issues on the programmatic or regional level whenever possible, and should further report on the considerations associated with issues not judged significant based on existing knowledge;

4. Administrative procedures and standards should be established for the identification and resolution of significant environmental issues disclosed subsequent to initial licensing decisions.

RECOMMENDATION 3

The panel recommends that government weather services and sea state information should be improved in accuracy, distributed more timely, and expanded to include potential and actual nodule mining areas in the Pacific, and hard mineral mining locations along the continental shelf.

RECOMMENDATION 4

The panel recommends that the government support research on the genesis of shell and placer deposits for the purpose of:

1. Evaluating the extent of deposits;

2. Identifying the process of generation of the resource;

3. Providing information which may help to develop environmentally sound mining and beneficiation systems;

4. Specifying controls on the technique with degree of removal of shell deposits so as to facilitate repopulation of shell beds for future mining; and,

5. Avoiding interference with littoral sediment transport which may have undesirable effects such as in beach erosion or wave refraction and possibly magnification.

RECOMMENDATION 5

The panel recommends that data should be acquired by the government for the preparation of high resolution bathymetric charts, with contour intervals of 5 to 10 meters for those areas of potential mineral deposits on the U.S. continental shelf.

RECOMMENDATION 6

The panel recommends that the federal government encourage the rapid development of the Navigation System with Timing and Ranging (NAVSTAR) global positioning system or its equivalent in order to meet the needs of the maritime user community, including the ocean mining industry. It also recommends that the federal government should foster the development of improved subsurface acoustical location fixing systems required for ships underway in planned ocean mining operations and related environmental investigations.

RECOMMENDATION 7

The panel recommends that the government should support research on equipment and techniques such as those described on pages 18-19 of this report in order to advance studies of resource assessment and mineral genesis.

RECOMMENDATION 8

The panel recommends that the federal government should promote the voluntary exchange of technical information among the ocean mining industry and relevant sectors of government and academic and research institutions.

Such information could include, but not be limited to:

-- The technology of high resolution sonar for sea floor imaging and/or topographic surveying,

-- The opportunities for and needs of particular sectors of the mining industry, and

-- The technology of sampling sea floor properties.

RECOMMENDATION 9

The panel recommends that the federal government should explore with other nations the feasibility of voluntary exchange of research information and of jointly planned and executed research programs for assessing environmental effects caused by ocean mining.

NOTES

1. Companies principally in Great Britain, Japan, West Germany, Belgium, and Canada.

2. Committee on Seafloor Engineering, Marine Board, Assembly of Engineering, National Research Council. Seafloor Engineering: National Needs and Research Requirements. National Academy of Sciences. Washington, D.C. 1976.

3. Panel on Operational Safety in Marine Mining, Marine Board, Assembly of Engineering, National Research Council. Mining on the Outer Continental Shelf and in the Deep Ocean. National Academy of Sciences, Washington, D.C. 1975

4. National Oceanic and Atmospheric Administration. Proceedings of the Marine Minerals Workshop, March 23-25, 1976, Silver Spring, Maryland. U.S. Department of Commerce. Washington, D.C. 1976.

5. U.S. Maritime Administration. National Planning Conference on the Commercial Development of the Oceans - Panel 2 - Hard Minerals. Unpublished outline notes. June 1976.

6. Johnston, James L. Unpublished. "Resource Availability and Projected Demand for Manganese Nodules." Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C. 1976.

7. Comptroller General of the United States. Deep Ocean Mining Environmental Study -- Information and Issues. Government Printing Office, Washington, D.C. 1976.

8. Gerard, R. "Environmental Effects of Deep-Sea Mining." MTS Journal, v. 10, n. 7, Washington, D.C., September 1976.

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9. Ocean Mining Administration. Ocean Mining, An Economic Evaluation. Department of the Interior, Washington, D.C., 1976.

10. Marine Industry Advisory Service. Offshore Mining of Sand and Gravel. Opportunity Brief No. 2. MIT Sea Grant Program, Cambridge, Massachusetts, 1976.

11. Stowasser, W.F. "Phosphate Rock." Mineral Facts and Problems, 1975 Edition. Publications Distribution Branch, Bureau of Mines, Pittsburgh, Pennsylvania, 1975.

12. Moore, J.R. "Marine Placers. State of the Art, Problems, and Recommendations." Paper presented at National Oceanic and Atmospheric Administration Workshop, Silver Spring, Maryland, March 23-25, 1976.

13. Duane, D.B., D. Fuerstenau, R. Gerard, and J. Herbich. Unpublished. "Geological Processes: Dynamics of the System." Prepared for the Marine Minerals Technology Workshop. 1977. Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

14. Brown, R., D. Fuerstenau, J.B. Herbich, R. Kaufman, R. Moore, and W. Normark. Unpublished. "Marine Mining Technology: Current Capability and Future Demands." Prepared for the Marine Minerals Technology Workshop. 1977. Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

15. National Materials Advisory Board, National Research Council. Manganese Recovery Technology. National Academy of Sciences, Washington, D.C. 1976.

16. Bischoff, James L., et al. "Deep Ocean Mining Environmental Study, N.E. Pacific Nodule Province, Site C, Geology and Geochemistry." U.S. Geological Survey Open File Report No. 76-548. Washington, D.C. July 1976.

17. Commission on Natural Resources, National Research Council. Perspectives on Technical Information for Environmental Protection. Vol. 1. Analytical Studies for the U.S. Environmental Protection Agency. National Academy of Sciences, Washington, D.C., 1977.

BIBLIOGRAPHY

Andrews, J.E. "Aspects of the Geologic Setting of Manganese Nodule Deposits," in Committee for Coordination of Joint Prospecting for Minerals in South Pacific Offshore Areas. Eds. G.P. Glasby and H.R. Katz. Papers presented at the IDOE Workshop, Suva, Fiji, September 1-6, 1975.

Bischoff, J.L., et al. Deep Ocean Mining Environmental Study, NE Pacific Nodule Province, Site C, Geology and Geochemistry, U.S. Geological Survey Open File Report No. 76-548, Menlo Park, California, 1976.

Dames and Moore. Task I Draft Report for On-Shore Processing of Manganese Nodules. EIC Corporation, Newton, Massachusetts, 1976.

Deepsea Ventures, Inc. Major Sources of U.S. Imports of Essential Materials. Deepsea Ventures, Inc., Gloucester Point, Virginia, 1975.

Ely, N. Statement before the Committee on Commerce, the Committee on Foreign Relations, and the Committee on the Armed Services, United States Senate on The Deep Seabed Hard Minerals Act. Deepsea Ventures, Inc., Gloucester Point, Virginia, 1976.

Federal Preparedness Agency. Stockpile Report to the Congress, January-June 1975. General Services Administration, Washington, D.C., 1976.

Finney, J.W. "U.S. In Major Shift, Sets Three-Year Supply in Strategic Stocks." The New York Times, October 2, 1976.

Fisher, A.C. and F. M. Peterson. "The Environment in Economics: A Survey." Journal of Economic Literature, XIV, No. 1, pp. 1-33, March 1976.

Hedgpeth, W.J. and S. Obrebski. "Ecosystems Models and Resource Management." The Coastal Society Bulletin (Preliminary Series 1[2]), pp. 5-10, 1976.

Herbich, J.B. "Methods for Offshore Dredging." Presented at the Sixth World Dredging Conference, WODCON VI, Taipei, Taiwan, October 1974.

Herbich, J.B. and W.S. Greene. "Bibliography on Dredging." Third Edition, Volume I, No. 2. Texas Engineering Experiment Station, Texas A&M University, College Station, 1975.

Herbich, J.B. "Dredging Methods for Deep Ocean Mineral Recovery." Journal of the Waterways, Harbors, and Coastal Engineering Division, American Society of Civil Engineers. New York. May 1971.

Herbich, J.B. "Coastal and Deep Ocean Dredging." Gulf Publishing Company, Houston, Texas, 1975.

Herbich, J.B. and W.K. Lou. "Stable Catamaran Hulls for Cutterhead Dredges." Offshore Technology Conference. Paper 2290. 1975.

Jet Propulsion Laboratory. Follow-on SEASAT User Needs Report. California Institute of Technology, Pasadena, 1976.

Johnston, J.L. "Seabed Minerals and the U.S. Economy: A Comment." MTS Journal, Vol. 11, No. 1 (January-February 1977).

Lane, A.L. NOAA's New Office of Marine Minerals. Presented at OCEANS '76, MTS-IEEE Conference, Washington, D.C., September 13, 1976.

MacCutcheon, E.M. and C.A. Burroughs. Trade-Off Procedure for Selective Emphasis in National Ocean Survey Program Formulation. Office of Systems Development, Washington, D.C., 1971.

Moore, J.R. and M.J. Cruickshank. "Identification of Technologic Gaps in Exploration of Marine Ferromanganese Deposits." Inter-University Program of Research on Ferromanganese Deposits of the Ocean Floor, Phase 1 Report, Seabed Assessment Program, International Decade of Ocean Exploration, National Science Foundation, Washington, D.C., 1973.

Moore, J.R. and C.J. Welkie. Metal-Bearing Sediments of Economic Interest, Coastal Bering Sea. Proceedings, Symposium on Sedimentation, Alaska Geological Society, Anchorage, 1976.

"Outlook for Marine Mining Clouded by Legal, Environmental, Other Problems." Chemical and Engineering News, pp. 30-31, November 15, 1976.

Raymond, R.C. "Seabed Minerals and the U.S. Economy: A Second Look." MTS Journal, Vol. 10, No. 5, pp. 12-18, 1976.

Schroeder, H.J. "Copper." Mineral Facts and Problems, 1975 Edition. Publications Distribution Branch, Bureau of Mines, Pittsburgh, Pennsylvania.

Stewart, R.J. "Oil Spills and Offshore Petroleum." Technology Review, pp. 47-60, February 1976.

Teltsch, K. "U.N. Law of Sea Meeting Recesses, Still Deadlocked on Mineral Riches." The New York Times, September 18, 1976.

Thomas, W.D. and P.S. Barracca. "The Salvor and the Prevention of Water Pollution by Marine Transportation." Fairplay International Shipping Journal (Tanker Salvage, Murphy Pacific Marine Salvage Company), March 29, 1973

U.S. Department of Commerce. Marine Mining Program. Government Printing Office, Washington, D.C. 1976.

__________, National Oceanic and Atmospheric Administration. User's Guide to NODC's Data Services, Key to Oceanographic Records Documentation No. 1 (revised). Government Printing Office, Washington, D.C. 1974.

__________. Federal Plan for Marine Environmental Prediction. Government Printing Office, Washington, D.C., 1976.

__________. NODC Applications Products. Government Printing Office, Washington, D.C., 1976.

__________. Proceedings of the Marine Minerals Workshop, March 23-25, 1976, Silver Spring, Maryland. Government Printing Office, Washington, D.C., 1976.

__________. Science and Engineering News from NOAA. Government Printing Office, Washington, D.C., August 1976.

U.S. Department of Interior, Bureau of Mines. Imports Supplied Significant Percentage of Minerals and Metals Consumption in 1975. Government Printing Office, Washington, D.C., 1975.

__________. Mineral Trends and Forecasts. Government Printing Office, Washington, D.C., 1976.

__________. Mining Technology Research. Government Printing Office, Washington, D.C., 1976.

__________. Research 75: A Summary of Significant Results in Mining Metallurgy and Mineral Economics. Government Printing Office, Washington, D.C., 1976.

__________. U.S. Imports and Exports of Raw and Processed Minerals. Government Printing Office, Washington, D.C., 1976.

__________. Commodity Data Summaries, 1977. Government Printing Office, Washington, D.C., 1977.

U.S. Department of Interior, Ocean Mining Administration. Manganese Nodule Resources and Mine Site Availability. Government Printing Office, Washington, D.C., 1976.

U.S. Senate, Committee on Interior and Insular Affairs, Sub-Committee on Minerals, Materials, and Fuels. Status Report on Law of the Sea Conference. Government Printing Office, Washington, D.C., 1976.

Vlezeboer, P.Th. "Some Comments on the Economics of Offshore Mining." Preprint from the Symposium on Offshore Hydrodynamics, Wageningen, August 25-26, 1971.

Weiss, A., Ed. "World Mining and Metals Technology. Vol. I." Proceedings of the Joint Mining and Metallurgical Institute of Japan-American Institute of Mining, Metallurgical, and Petroleum Engineers Meeting, Denver, Colorado, September 1-3, 1976.

Wilkins, W.D. and D. Persuad. "Open Water Material Disposal Monitored." World Dredging, pp. 36-38, August 1976.

Williams, O.W. (Unpublished). "The NAVSTAR Global Positioning System and a First-Order Framework for Information Systems." Presented to the American Congress on Surveying and Mapping, University of Maine, Orono, August 25-27, 1976.

APPENDIX A

Unpublished Working Papers Prepared for The Panel on Marine Minerals Technology

Brown, R., D. Fuerstenau, J.B. Herbich, R. Kaufman, R. Moore, and W. Normark. "Marine Mining Technology: Current Capability and Future Demands." Prepared for the Marine Minerals Technology Workshop. 1977. Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

Duane, D.B., D. Fuerstenau, R. Gerard, and J. Herbich. "Geological Processes: Dynamics of the System." Prepared for the Marine Minerals Technology Workshop. 1977. Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

Harris, L.G. 1976. "Environmental Assessment of Marine Mining." Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

Johnston, James L. 1976. "Resource Availability and Projected Demand for Manganese Nodules." Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

Kaufman, R. 1976. "National Needs, Current Capabilities, and Engineering Research Requirements (Offshore Mining Industry)." Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

MacCutcheon, E.M. 1976. "Technical Deficiencies and Improvement Opportunities in Marine Mining." Available from the Marine Board, Assembly of Engineering, National Research Council, Washington, D.C.

APPENDIX B

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